Mapping, Meaning, and Motion: An Artistic Framework for Visualizing Movement Quality

by

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Dissertation Submitted In Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy

in the

School of Interactive Arts and Technology
Faculty of Communication, Art and Technology

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SIMON FRASER UNIVERSITY

SPRING 2015

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Abstract

This dissertation presents the development of an artistic framework for visualizing movement quality that is composed of a series of artistic visualization systems, a set of design strategies for aesthetically representing movement quality information, and evaluative studies of the movement experts’ experience in perceiving movement quality visualization. In digital technology contexts, movement quality information can be accessed and obtained by exploring the semantics of an expressive motion framework called Laban Movement Analysis (LMA) as well as the use of computational techniques to measure, analyze, and capture this type of information from the human body in motion. LMA has broad application across research fields of art computing (e.g., character animation, gesture recognition, interaction design, robotics, visual language, interactive arts, and game design). However, the integration of LMA within the visualization domain is still under exploration, and there are no contributions in that domain for representing high-level semantic information such as movement quality.

This thesis’ research aims to develop understanding of how LMA can be used as a semantic design resource for visualizing movement qualities by (1) outlining potential visual mapping to represent movement qualities and (2) creating a set of design heuristics for abstract visual representation of movement quality. To generate better understanding of how LMA can be artistically applied to visualization contexts, practice-based research was used as an approach to developing a series of visualization systems that used LMA as an underlying model to capture, represent, and map movement quality to a visualization system. Movement experts were selected to participate in evaluation of the visualization systems, and the comparative analysis method was used to critique, analyze, and compare these visualization systems.

This study contributes new knowledge gained from art practice by illustrating how movement theoretical models and movement expertise can be modified and adapted to the design and application of more richly articulated human movement knowledge within the visualization domain. Finally, the study provided a set of design heuristics comprised of eight design guidelines for representing eight movement qualities. These design guidelines can be applied and further explored in various areas, such as visual communication design, abstract animation, and movement analytics.

Keywords: Artistic Visualization Framework; Movement Quality Visualization; Laban Effort Visualization; The eight Basic Effort Actions visualization
For my family, for love, patience, and support.
Acknowledgements

I gratefully thank my supervisors, Dr. Thecla Schiphorst and Dr. Philippe Pasquier for their guidance and continued support, inspiration, and encouragement during my Ph.D. study. I also offer my sincere appreciation for the opportunity to work as a research assistant and the learning opportunities provided by my supervisors, as well as the funding provided by the movingstories research project. I also sincerely thank Dr. Lyn Bartram and Dr. Donna J. Cox for their comments, suggestions, and compliments on my Ph.D. thesis. It is my honour to have both of you as an internal examiner and external examiner for my Ph.D. defence.

I would like to thank my parents for their understanding, support, and encouragement during many years of my study abroad. I must also thank Bangkok University for providing a full scholarship for my Ph.D. study.

I thank Professor Karen Bradley (UMD) and Professor Karen Studd (GMU) for helping me gather movement data and recruit movement experts to participate in my study, as well as those CMAs who participated and spent hours on my research experiment. I also thank Simon Fraser University and the School of Interactive Arts and Technology for providing me various grants and scholarships.

I gratefully thank my friends and colleagues Diego Maranan, Kristin Carlson, Laura Lee Coles, Greg Corness, Chao Feng, John Wang, Camille Wang, Parjad Sharifi, Suk Kyoung Choi, and the people from the movingstories research project for their support and friendship - “Thank you all of you guys for awesome ideas, encouragements, and support on my thesis project.” I also thank Annique-Elise Goode for helping me proofread my thesis.

Last but not least, I would like to thank SIAT staff Gordon Pritchard and Larry Soo for technical support on web server and computer issues, as well as Tiffany Taylor and Joyce Trammell for their support in the graduate program. Finally, my apologies, I thank those I may have missed in my acknowledgement.
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List of Acronyms

ANOVA  Analysis of Variance
BEAs   Basic-Effort-Actions
BESS   Body, Effort, Shape, Space
CMA    Certified Movement Analyst
CMH    Cochran-Mantel-Haenszel
CTV    Communication Through Visualization
DataVis Data Visualization
EMVIZ  Effort, Mapping, Meaning, and Motion Visualization System
HCI    Human Computer Interaction
InfoVis Information Visualization
LIMS   LABAN/BARTENIEFF Institute of Movement Studies
LMA    Laban Movement Analysis
L-system Lindenmayer System
NSAD   National Association of Schools of Dance
RQ     Research Question
SciVis Scientific Visualization
Glossary

Artistic Visualization
In a broad sense, *artistic visualization* is defined as “the use of computing as a medium in combination with art theory and artistic process with the intention to explore creative design space for art-making, in order to provide sensory outcomes (either readable or non-readable), new visual experiences, and some useful functions to a viewing audience” (see p.65).

Certified Laban Movement Analyst (CMA)
*Certified Laban Movement Analyst* (CLMA) or CMA refers to the movement practitioners and educators who studied and received a certification at the LABAN/BARTENIEFF Institute of Movement Studies (LIMS), an accredited institutional member of the National Association of School of Dance (NSAD). A Certified Movement Analyst has both theoretical and practical knowledge of Laban Movement Analysis and understands how it is applied in various fields and contexts. (See: Laban/Bartenieff Institute. (2009). Services | Certified Movement Analysts. Retrieved July 4, 2013, from http://www.limsonline.org/services-certified-movement-analysts).

Cochran-Mantel-Haenszel (CHM)
*CHM* is a statistical test for detecting the association between two categorical variables observed in K strata.

Comparative Analysis
*Comparative analysis* refers to the systematic study and analysis of a small number of cases that focus on similarities and contrasts among cases (Collier, 1993). It provides high-level discussion that evaluates relevant similarities and differences between two or more cases by revealing the strength and weakness of each case.

Contemporary Visualization
In this thesis, *contemporary visualization* refers to the visualization research community’s main streams and their subfields, such as data visualization, information visualization, scientific visualization, knowledge visualization, visual analytics, and geovisualization.

Design Exploration
*Design exploration* is a research activity focused on exploring, searching, and analyzing for design possibilities outside of current research paradigms through critical analysis and experimentation to reveal alternative design solutions. Design exploration can be compared to the ideals of contemporary art or *avant-garde* and usually focuses on issues of aesthetics and experiences (Fallman, 2011).
Diagonal Scale  

*Diagonal Scale* is a concept devised by Rudolf Laban, that describes the extremes of far-reaching space that crisscross the body’s centre from one corner of a three-dimensional cube to the opposite corner (Bradley 2008). When Diagonal Scale is applied in movement practice, it allows dancers or movers to explore the extremes of personal space.

Effort  

*Effort* is considered the dynamic or qualitative use of energy, texture, colour, emotions or inner attitude of movement. (Hackney, 1998; Maletic, 2005). Effort reflects the changes of the mover’s attitude towards investing energy in four basic factors: Space, Weight, Time, and Flow (Bradley 2008; Hackney, 1998). In this thesis, the term *Effort* is used interchangeably with movement quality.

Effort Affinities  

*Effort affinities* describe dimensional cross and its extremes within Laban’s dynamosphere, a three-dimensional cube that shows the dynamics of the Basic-Efforts (movement qualities) and their relationship to each other within the Kinesphere (Newlove & Dalby 2004, p.141). For instance, the vertical dimension is affined with Weight, which is a continuum bounded between two extremes (Light and Strong). Light’s affinity motion path is upward, while Strong’s affinity motion path is downward (see Bradley 2008, p.91).
Effort Factors

*Effort Factor* is a continuum bounded by two extreme values, called Effort Parameter Values (see below [Laban & Lawrence, 1974]).

Effort Parameter Values, Effort Elements, or Effort Qualities

*Effort parameter values* are two extreme values of Effort Factor. The value at one end of the continuum is the result of "indulging" through the Effort, while the value at the other end is the result of "fighting" or "condensing" through the Effort (Laban & Lawrence 1974). These values are interchangeably called Effort elements, Effort qualities, and Effort parameter values (Hackney, 1998, p. 239; Laban & Lawrence 1974). Space is either Direct or Indirect. Weight is either Strong or Light. Time is either Sudden or Sustained. Flow is either Bound or Free.

Eight Basic Effort Actions (BEAs)

The eight Basic-Effort-Actions are the combination of three Effort Factors (Space, Weight, and Time) resulting in eight possible Effort combinations, called the Action Drive. In the Action Drive, the extreme values of Space, Time, and Weight combine to create eight movement qualities: Float, Punch, Glide, Slash, Dab, Wring, Flick, and Press (Laban & Lawrence 1974). These movement qualities are so prevalent in daily activity that Laban calls them the Basic-Effort-Actions (BEAs).

Alaoui et al. (2014) state that, “BEAs are not to be conflated with gestures, which are defined in LMA as a meaningful movement of a single isolated body part from the core (e.g. waving the hand or nodding the head). Thus, it is important to abstract the BEAs from metaphorical gestural actions and cues such as clenching the fist when punching, because the BEAs may be performed or observed in both full postural effortful actions and in gestural actions of one body part” (Alaoui et al., 2014).

Evaluating Communication through Visualization (CTV)

*CTV* is the assessment of the visualization’s communicative value. It focuses on the study of how communication can be supported by visualization. The main goal is to measure how effectively such messages or information are delivered and acquired by individuals or groups (Lam et al., 2011).

Kinesphere

The *Kinesphere* concept describes the mover’s own personal space (i.e., from near the body to the far-reaching space) and the movement initiation within the mover’s Kinesphere that can psychologically affect the audience (Hackney, 1998).
Movement Quality

Movement quality refers to the manner or characteristics in which the movement is executed (Fdili Alaoui & Serrano 2011). In this thesis, the term movement quality is used interchangeably with Effort.

Practice-Based Research

Practice-based research is a research activity that investigates and contributes to creating new knowledge grounded on practice and the outcomes of that practice. This type of research is usually referred to as reflection practice, reflective practice or reflection-in-action. Donald Schön, a philosopher and educator, defines these terms as “the process of thinking which accompany doing, and which constantly interact with and modify ongoing practice in such a way that learning takes place” (Schön, 1983).

Semantic Information

In general, semantic information relates to the study of meaning or the interpretation of meaning in linguistics. It refers to the study of meaning in gesture and movement, and the qualitative aspect of movement obtained from movement observation. In this thesis, movement quality is considered high-level semantic information.

Visualization Exploration

Visualization exploration refers to research activities often driven by the artist’s or designer’s own research agenda, that attempt to experiment with unconventional design processes and demonstrate design possibilities in order to create new visualization design solutions.

Visualization Readability

Visualization readability refers to how much of the information is communicated or how easy the outcome of visualization is to read, understand, communicate, and draw the meaning out of the dataset when the viewer know the visualization context (see Chapter 2, section 2.2.2.4.)
Kristin Carlson performed Punch Effort (Direct, Strong, and Sudden) and Punch visualization generated by EMVIZ (Motion-Agent) system at ACM CHI Conference on Human Factors in Computing Systems: The User in Flux Workshop Exhibition (May 7, 2011) © 2011 Pattarawut Subyen.
Chapter 1.

Introduction

The application of human movement within digital technology has been extensively researched, borrowing from many disciplines, such as biomechanics, mathematics, anatomy, psychology, neuroscience, kinesiology, and the visual and performing arts. Recent research projects in Human Computer Interaction (HCI) have investigated and explored how human movement can be integrated into digital technology contexts. This led to the development of new tools, theoretical models, and computational techniques for capturing, analyzing, and visualizing the complexity of human movement in various fields of art and computing, such as character animation, interactive arts, game design, interaction design, gesture recognition, visualization, and robotics. This advancement provides us with a better understanding of how movement knowledge and human experience can be applied in other research domains. However, there is a research gap in exploring how movement theoretical models and movement expertise can be modified and adapted to the design and application of more richly articulated human movement knowledge within digital technology contexts, especially in the visualization discipline.

The work presented in this thesis was undertaken within the MovingStories research project\(^1\), an interdisciplinary, collaborative research partnership leading to the design and application of more richly articulated human movement knowledge within digital technology interaction. The MovingStories research project primarily focuses on the exploration of methods for recognizing, extracting, and analyzing somatic movement.

\(^1\) MovingStories research is directed and led by Dr. Thecla Schiphorst (Research Director) and Dr. Philippe Pasquier (Research Committee). The project is funded and supported by the Social Sciences and Humanities Research Council of Canada (SSHRC), see: http:www.movingstories.ca
data based on the Laban Movement Analysis Framework (LMA)\(^2\), in order to develop models for utilizing meaning in movement for interaction, computation, and media representation (Schiphorst et al., 2011). This thesis is situated in the area of human movement and visualization wherein the main focus is visualizing high-level semantic movement information (i.e., movement quality). In contemporary dance, movement quality refers to the manner or ways in which the movement is executed (Alaoui et al., 2012a). In the LMA framework, movement quality is defined through its Effort such as Direct, Indirect, Strong, Light, Sudden, and Sustained (see Chapter 4, section 4.1). Rudolf Laban saw Effort or movement quality as the inner impulse—a movement sensation, thought, feeling or emotion—from which movement originates; it constitutes the interface between the mental and physical components of movement (Maletic, 2005). Thus, movement quality is considered high-level semantic information that tends to be recognized by experts who have experience or training in movement practices.

This thesis presents practice-based art research conducted by the author in collaboration with movement experts and computer scientists in order to design and develop a visualization system for representing movement quality. This research involved the creation of artworks, the development of an artistic framework for visualizing movement quality, a design strategy and design criteria for aesthetically representing movement quality information, and evaluative studies of the movement experts’ experience in perceiving movement quality visualization. This resulted in the creation of three artistic visualization systems–EMVIZ (L), EMVIZ (Sketch), and EMVIZ (Motion-Agent), respectively–and an artistic framework for visualizing movement quality.

Movement quality data was obtained from a real-time wearable sensor classifier supervised learning system that applied an LMA model to extract movement qualities from a moving body in the form of Laban Basic-Effort-Actions (BEAs) (see Chapter 4, section 4.2). The three EMVIZ visualization systems used the same input data but different metaphoric mapping approaches, design processes, and computational algorithms for representing movement quality. EMVIZ (L) and EMVIZ (Motion-Agent)

were exhibited as interactive installations and interactive dance performances, while EMVIZ (Sketch) was used as a visual dashboard during the movement recognition system evaluation. In the evaluation process, we asked domain experts (Certified Laban Movement Analysts\(^3\)) to evaluate the communicative ability of EMVIZ (L), EMVIZ (Sketch), and EMVIZ (Motion-Agent) in conveying the eight Basic-Effort-Actions through abstract expressive animations or visualizations.

1.1. The Aims of Research

As a visual designer with degrees in visual communication design and computer art, I have always been interested in computational art and visualization design in regards to the process for generating aesthetically pleasing abstract animations or visualizations. In my artistic practice, I use computers as a medium to explore and combine the elements of my design process (e.g., metaphor, computation, art theory, and aesthetic) for visual generation. In the visualization domain, I am particularly interested in the visualization discipline, interchangeably called artistic visualization, aesthetic visualization, aesthetic information visualization or visualization art. This discipline emerged from interdisciplinary branches of science and was inspired by art and technology domains, such as new media art, digital art, interactive art, visual art, social sciences, computational art, and generative art.

In the artistic visualization domain, several projects have investigated, explored, and visualized various data types, such as weather, emotion, music patterns, population, film, flight patterns, political connections, and social networks (Koblin and Klump, 2010; Paul, 2008; Pousman et al., 2007; Salavon, 2000; Wattenburg, 2001). I am particularly interested in data types related to semantic information, mental experience or sensory perception, such as emotion, music, and human movement. These types of data usually have underpinning theoretical models or theories, which makes the design process more interesting to explore and investigate how to incorporate and utilize such models for

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\(^3\) Certified Laban Movement Analysts (CLMA) or CMA are movement practitioners and educators who studied and received certification at LABAN/BARTENIEFF Institute of Movement Studies (LIMS), an accredited institutional member of the National Association of School of Dance (NASD). A Certified Movement Analyst has knowledge of Laban Movement Analysis (both in theory and practice) and understands how it is applied in various fields and contexts, see: Laban/Bartenieff Institute. (2009). Services | Certified Movement Analysts. Retrieved July 4, 2013, from http://www.limsonline.org/services-certified-movement-analysts).
analyzing, recognizing, and capturing data for visualization systems. For instance, emotion and music visualization research often employs and extends Ekman’s six basic emotions (Ekman, 1999; Ekman et al., 1980), Russell’s circumplex model of affect (Russell, 1980) or a neurological condition called synaesthesia⁴ (Cytowic, 1995). In movement and gesture, several research areas in computing (e.g., character animation, interactive arts, game design, gestural interface design or robotics) used the LMA framework as a model for capturing, analyzing, and understanding human movement.

The search results from the ACM guide to computing literature⁵ included several extensively researched projects related to emotion and music visualization. For human movement, most projects focused on enabling users to interact, control, and generate visualizations using movement properties, such as spatial dimensions, trajectory, direction, speed, and acceleration (Gutknecht et al., 2008; Ip et al., 2002; Latulipe and Huskey, 2008; etc.). However, a few projects explored and visualized semantic human movement information (see Chapter 2). For instance, Carlson et al. presented a human movement analytical tool that visualized choreographic information in different pieces of contemporary dance choreography (Carlson et al., 2011a). Palazzi et al. created an interactive screen-based visualization application that unfolded choreographic structures by William Forsythe, one of the world’s foremost choreographers (Palazzi et al. 2009). For this reason, I believe that there is potential to expand research in the area of human movement and visualization. Thus, I set a personal goal to explore human movement and artistic visualization domains in order to construct my research’s conceptual framework, goals, questions, design, and contributions.

This thesis began with curiosity about how movement quality could be represented through dynamic abstract animations or visualizations. Quality, in this case, refers to the properties or distinctive characteristics of movement. The answer to such a question is usually derived from observation and verbal or written description. Therefore, to visualize or represent movement quality, which is semantic information, is a

⁴ Synaesthesia is a neurological condition in which stimulation of one sensory or cognitive pathway leads to automatic, involuntary experiences in a second sensory or cognitive pathway (Cytowic 2002). For instance, seeing a colour from hearing a certain sound, see: Richard E. Cytowic, Synaesthesia: Phenomenology And Neuropsychology: A Review of Current Knowledge, PSY CHE, 2(10), July 1995.

⁵ The ACM guide to computing literature is currently the most comprehensive bibliographic database focused exclusively on the field of computing, see: http://dl.acm.org
challenging task because it requires the integration of different elements (e.g., theoretical models, computation or artistic choices) to form design criteria for representing this semantic information. However, the LMA framework describes theoretical movement foundations and provides the categorization of eight movement qualities, called the eight Basic-Effort-Actions (see Chapter 4 section 4.1), which can be used as a reference or underlying model for representing human movement quality. Moreover, there was an opportunity to explore the LMA framework within the artistic visualization domain. Thus, I based this thesis’ personal, practical, and scholarly goals upon human movement study and artistic visualization.

The aim of this research is to develop understanding of how LMA can be used as a design resource to create an artistic visualization system that generates abstract expressive visual representations of human movement quality or the eight Basic-Effort-Actions described in LMA Effort theory. Practice-based research was used as an approach to developing a series of visualization systems for visualizing movement quality. This has generated better understanding of how LMA Effort theory can be artistically applied to visualization contexts and used as an underlying movement model to capture, map, and represent high-level semantic movement information (i.e., movement quality) in a visualization system. This practice-based research also contributes to the creation of an artistic framework that describes an underlying model for capturing and mapping movement qualities to a visualization system, an evaluation methodology, and the ability to communicate information through a movement expert’s (Certified Laban Movement Analyst) experience.

This thesis bridges human movement study in art, design and computation with the artistic visualization domain. The intended audience includes the dancers, performers, artists, and researchers who apply LMA Effort to their artistic or creative works in digital technology contexts. It will be of interest to computational and visualization artists who explore or combine interpretive metaphoric mappings with aesthetic approaches to represent data from one domain to another, primarily the visual domain. In a broader context, this research is also associated with several research communities and conferences, such as “The International Symposium on Computational
1.2. Research Contexts

This section presents the conceptual framework grounding this thesis and briefly introduces related literatures that are discussed in detail in Chapter 2. The conceptual framework is divided into two primary categories: 1) human movement study in art, design, and computation; and 2) artistic visualization.

The human movement study in the art, design, and computation category reviews (1) human movement study within artistic practice, (2) movement theory used to analyze and describe the qualitative aspects of human gesture and movement, and (3) various human movement visualization projects. This category aims to identify missing elements in the literature (i.e., LMA Effort utilization within visualization domain) and create the research context for this thesis.

The artistic visualization category reviews the state of the art of visualization research, analyzes the characteristics of artistic visualization, and provides various examples of artistic visualization projects. This category aims to locate this thesis within the artistic visualization domain and to use artistic visualization characteristics to frame the direction of artistic human movement visualization research. Figure 1.1 presents this thesis' conceptual framework.

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6 Computational Aesthetic conference (CAe) investigates the creation of tools that integrate aspects of computer science, philosophy, psychology, and the fine, applied and performing arts, in order to enhance our understanding of aesthetic evaluation, perception and meaning, see: http://www.computational-aesthetics.org

7 SIGGRAPH is an international community of researchers, artists, developers, filmmakers, scientists, and business professionals who share an interest in computer graphics and interactive techniques, see: http://www.siggraph.org

8 EVA London is a conference that focuses on the development and application of visualization technologies, including art, music, dance, theatre, and the sciences, see: http://www.eva-london.org

9 International Conference Information Visualization is a well-known conference with a wide range of research topics in visualization, such as medical visualization, information visualization, scientific visualization and visualization and art, see: http://www.graphicslink.co.uk

10 IEEE VIS Art program is a part of the IEEE VIS conference that aims to explore the relationships between visualization research and artistic visualization practice, see: http://ieeevis.org
1.2.1. Human Movement Study in Art, Design, and Computation

Since the ancient Greeks, human movement has been studied in interdisciplinary areas related to art and design, such as psychology, mathematics, and anatomy (Klette and Tee, 2008). In art and design, prior research and artworks dealing with human motion focused on conveying or representing human motion or movement information, such as body, space, and time.

In digital technology, human movement research has shifted the focus to the creation of different tools, methods, technologies, and computations for extracting and analyzing movement information from the human body. Several researchers have investigated how to analyze and measure the fundamental properties of human movement using different types of sensors, such as touch (i.e., pressure sensor), position (e.g., camera, Kinect, Wiimote IR camera, and IR-based motion capture systems), and biometry (e.g., eye-tracking, breath sensors, EMG, and heart rate sensors). These tools and methods can measure different properties of human movement, such as the position, velocity, and acceleration of specific body parts (Schiphorst et al., 2011). In the interactive arts domain, these movement properties have been used in installations and performance artworks that enable users to interact, control, and create sound or visualizations by using gestural properties, such as spatial dimensions, trajectory, speed, and acceleration.
By using computational techniques to measure the fundamental properties of human movement, the complexity of movement information or properties (e.g., postural changes or energy expenditure) can be accessed. Additionally, high-level semantic movement information (i.e., movement qualities) can also be obtained by exploring the semantics of expressive motion frameworks or movement analysis systems. For instance, LMA provides rigorous explanatory models for the description of movement (Bartenieff et al., 1970; Bradley, 2008; Laban, 1974) and it has a rich epistemological history, particularly in the domains of dance, non-verbal communication, psychoanalysis, and psychology.

LMA has been—and continues to be—widely used in art and computing research. Examples include: character animation (Badler et al., 1999; Bishko, 2007; Chi et al., 2000; J. Kundert-Gibbs and K. Kundert-Gibbs, 2009); visualization of dance and planning choreography (Calvert et al., 2005; Carlson et al., 2011b); emotional expression in robots (Masuda et al., 2009; Nakata et al., 2002; Rett et al., 2010; Sharma et al., 2013); human gesture recognition and expressive gestures in multimedia systems (Alaoui et al., 2014; Arístidou and Chrysanthou, 2013; Camurri et al., 2004, 2009; Hachimura et al., 2005; Pietrowicz et al., 2010; Swaminathan et al., 2009; Volpe, 2003); visual language design for interaction representation (Deray, 2007); game design (Barakova and Lourens, 2010; Zacharatos et al., 2013); and HCI, interaction design, and interactive art (Alaoui et al., 2012b; Françoise et al., 2014; Loke and Robertson, 2010; Loke et al., 2005, 2007; Mentis and Johansson, 2013; Schiphorst, 2005, 2008, 2009; Schiphorst and Seo, 2011).

While LMA has broad interdisciplinary application, a literature review (see Chapter 2) indicated that Effort (i.e., one of four LMA components [see Chapter 2]) is the most utilized LMA component across many research areas. However, the possibility of integrating LMA Effort into the fields of art, design, and visualization is still under exploration. Thus, there is a research gap for articulating how to use LMA as a design resource for visualizing movement quality or use LMA Effort as an underlying model to capture, represent, and map high-level semantic movement information (i.e., movement quality) to a visualization system.
1.2.2. **Artistic Visualization**

In the last ten years, visualization has become a popular research area because the advancement of digital technology produced a large and complex collection of datasets that are difficult to process. Thus, the development of the processes, computational algorithms, and applications that generate visual representations for reinforcing human cognition and perception has been extensively explored. In the late 20\textsuperscript{th} century, scientific visualization and information visualization were the two main streams in the visualization research community. However, new subfields have emerged from these two streams, such as geovisualization, biomedical visualization, visual analytics, and knowledge visualization. For instance, in the digital art and interactive arts domains, a visualization discipline emerged that was inspired by new media, digital, and interactive arts. This new field is often interchangeably called data art, aesthetic visualization, aesthetic information visualization, visualization art, artistic visualization or art-inspired visualization. In this thesis, I use the term “artistic visualization” when referring to this field and the term “contemporary visualization” when referring to information visualization, scientific visualization, knowledge visualization, data visualization, and other visualization subfields.

Various concepts, models, and classifications have been used to define the characteristics or criteria of artistic visualization and thus distinguish artistic visualization from contemporary visualization. Artistic visualization’s characteristics and criteria have been widely discussed in the literature (Fishwick, 2006; Kosara, 2007; Lau and Moere, 2007; Manovich, 2002, 2008; Pousman et al., 2007; Ramirez, 2010; Sack, 2007, 2011; Skog, 2006; Viégas and Wattenberg, 2007; Whitelaw, 2008). For instance, artistic data visualization (1) uses actual data rather than metaphors, (2) focuses on aesthetics based on artistic intent, (3) expresses the artist’s point of view to persuade or change the way people think, and (4) is used by an artist with the intention of making art (Viégas and Wattenberg, 2007). Aesthetic visualization usually (1) concerns the attractiveness of data representation, (2) focuses on questioning or restructuring particular topics rather than resolving issues, and (3) uses visual metaphors that need not be easily decipherable or aesthetically pleasing, as long as they reflect the artistic intention or research objective (Ramirez, 2010). However, these characteristics were described and categorized differently, depending on the perspectives of artists or researchers. Thus,
there is a gap for articulating or reviewing the current state of the art produced by the artistic visualization domain.

To situate this thesis within the artistic visualization domain, this thesis reviews the state of the arts based on the concepts, models, and frameworks proposed by visualization artists and researchers. This has contributed to providing (1) a description of artistic visualization, (2) the characteristics of artistic visualization, and (3) examples of artistic visualization projects. All three contributions were used to frame the direction of this thesis.

1.2.3. **Summary: Artistic Human Movement Visualization**

Taking these two categories together, my literature review identifies a research gap for articulating how to use LMA Effort as a design resource for visualizing movement quality or as an underlying model to capture, represent, and map high-level semantic movement information (i.e., movement quality) to a visualization system. Artistic visualization characteristics were used to frame the design process (i.e., exploratory approach [see Chapter 3]) of this thesis and describe how this research is situated in artistic visualization domain.

1.3. **Research Questions**

In this thesis, I ask the following questions:

1. How can Laban Movement Analysis (LMA) be used as a semantic design resource for visualizing movement Effort qualities by:

1.1. using metaphor theory to outline potential visual mapping strategies to represent Laban Effort qualities, specifically the Basic-Effort-Actions?

1.2. creating a set of design heuristics for abstract visual representation of movement quality based on the analysis of movement experts’ perceptions of the communicative ability of different visual mapping approaches?

To answer these two questions, I created three artistic visualization systems called EMVIZ (L), EMVIZ (Sketch), and EMVIZ (Motion-Agent) respectively, and an
artistic framework that described and articulated how LMA Effort can be applied as an underlying model to capture, map, and represent movement quality to a visualization system. I also presented a methodology for evaluating and validating the results of this research.

To evaluate the communicative ability of the three iterations of the EMVIZ visualization system in conveying movement quality through abstract expressive animations or visualizations, I conducted a user study by recruiting 12 Certified Laban Movement Analysts (CMAs) to evaluate the three EMVIZ systems' communicative abilities. The CMAs were asked a series of questions in order to validate the LMA Effort system under evaluation as well as the CMAs' ability to recognize and evaluate movement or Effort qualities based on their training in recognition of movement quality and the eight Basic-Effort-Actions. This process helped to make evaluation results valid and consistent (see Chapter 5, section 5.2). The survey results reported both descriptive and inferential statistics (quantitative) and in-depth description and explanation (qualitative) derived from participant feedback. Comparative analysis among the three EMVIZ systems was also performed in order to bring deep analysis and further discussions to answering question 1.2.

1.4. Practice-Based Research Approach

The research questions were investigated and explored through practice-based research, which is a process of thinking accompanied by doing in such a way that learning takes place (Schön, 1983). This is also known as reflective practice (i.e., knowing-in-action) and attempts to bridge traditional research and practice. This process focuses on thinking and reshaping action while practicing and the outcome is to know how rather than to know what (Gray and Malins, 2004; Schön, 1983). In art and design, this process is contextualized as practice-based arts research, a research activity that investigates and contributes to creating new knowledge grounded on art practice and its outcomes (Candy, 2006; Candy and Edmonds, 2010). This new knowledge is the production of critical thinking and creativity emerging from individual, social, and cultural inquiry (Sullivan, 2009). The central activity of practice-based arts research is the designing, developing, and art-making of artefacts, such as images, music, designs,
models, digital media, performance, and exhibitions (Candy, 2006; Candy and Edmonds, 2010).

In this thesis, I employed practice-based research as a strategy to (1) understand the research context and explore visualization design strategies, (2) develop a movement quality visualization framework, (3) create a series of artistic movement quality visualization systems, (4) evaluate the movement quality visualization systems, and (5) establish an artistic framework for representing movement quality. In this process, practice and research activities moved through several stages of creation and evaluation, such as formulating a research question, generating design strategies, and testing artefacts (Edmonds and Candy, 2010). Figure 1.2 presents the three elements and five stages of my research in movement quality visualization, illustrating the relationship between theory, practice, and evaluation.

Figure 1.2. The three elements and five stages of thesis research

Note. Adapted from (Edmonds and Candy, 2010).
In the evaluation process, I conducted a user study to evaluate the communicative ability of three versions of the EMVIZ visualization system to convey movement quality through abstract expressive animations or visualizations. I detail my research methodology, methods, techniques, and evaluation process in Chapter 3.

1.5. Contributions of the Research

The contributions of this thesis are separated into four main categories: 1) an artistic framework for visualizing movement quality; 2) definition and characteristics of artistic visualization, 3) LMA Effort validation; and 4) a set of design heuristics for abstract visual representation of movement quality. Figure 1.3 summarizes and illustrates these contributions, and each contribution is briefly described in the following sections.

![Figure 1.3. A diagram of research contributions of this thesis](image-url)
1.5.1. An Artistic Visualization Framework for Visualizing Movement Quality

The primary contribution of this thesis is an artistic framework for visualizing movement quality, and its elements can be categorized into four main groups: capture, map, represent, and evaluate. Each group is described as follows:

**Capture:** I proposed the possibility of using EffortDetect (a real-time wearable sensor classifier-supervised learning system that applies LMA Effort to extract movement qualities from a moving body in the form of Laban Basic-Effort-Actions) within the artistic visualization domain (see Chapter 4). The contribution is not the EffortDetect system design itself but the applied use of LMA Effort as an underlying movement theory for capturing movement quality information. It illustrates the possibility of incorporating a movement quality recognition system with the design and implementation of a visualization system.

**Map:** In this process, I articulated how LMA Effort can be used as a design resource for mapping movement quality data obtained from EffortDetect to a visualization system. I used an exploratory approach to design three visual mapping strategies that created three EMVIZ systems. These strategies applied movement quality characteristics derived from LMA Effort using metaphor theory, visual art theory, colour theory, and generative computation to generate abstract expressive representations of eight movement qualities. This contributed design strategies, tools, and techniques for representing the human movement quality information described in LMA Effort theory, which benefits research literature involved with LMA utilization in the artistic visualization domain, specifically design approaches for representing movement quality.

**Represent:** I presented different styles of the representation of eight movement qualities generated by three different versions of the EMVIZ visualization system. This contributed new knowledge grounded in art practice, critical thinking, and creativity emerging from my design experience and collaboration with movement experts and computer scientists. EMVIZ (L) and EMVIZ (Motion-Agent) were exhibited as an interactive installation and interactive dance performance (respectively), while EMVIZ (Sketch) was used as a visual dashboard during EffortDetect system evaluation. New
knowledge and answers to thesis research questions are embedded in these three creative artefacts.

Evaluate: I provided evaluation approaches used to evaluate artistic visualization and presented the study design and the evaluation approach, composed of statistical analysis, participant feedback, and comparative analysis to evaluate the artistic visualization project. The evaluation approach in this thesis contributed to the artistic visualization research literature. In this process, I recruited movement analysts (i.e., CMAs) to participate in the study and used online survey as a data collection tool. Online survey is not often used for project evaluation employing CMAs, because most projects usually ask the CMAs to give direct feedback at the research site. This research offered a preliminary evaluation approach that allows participants who live far away from research sites to participate in the evaluation. This approach contributes to the literature on applied LMA in research evaluation, such as HCI, robotics, animation, and gesture recognition.

1.5.2. Characteristics and Definition of Artistic Visualization

In Chapter 2, I review the state of the art of visualization research and several concepts that attempt to define the characteristics or criteria of artistic visualization. These characteristics were analyzed and classified into four main categories: data type, artistic goal, design process, and outcome and visual experience. I also provide an artistic visualization definition derived from this analytical process. Broadly speaking, these characteristics describe how artistic visualization is different from other visualization domains. In this thesis, these characteristics frame the direction of my practice-based art research and describe my data mapping design process and how movement quality visualization is situated within the artistic visualization domain. This literature review section contributes to the visualization research literature by providing a broad definition and better understanding of the artistic visualization domain’s characteristics.

1.5.3. LMA Effort Validation

In Chapter 5, I attempt to validate both the LMA Effort framework and the ability of trained CMAs in the experiment, although the LMA Effort framework is a well-
respected theory and CMAs are known for their expertise in theory and practice in the LMA framework. CMAs are often recruited to evaluate research projects that integrate the LMA framework within the project (e.g., HCI, robotics, and gesture recognition). However, none of these research projects focused on CMAs’ observational skills and whether they were accurate and consistent. If the LMA Effort framework and CMAs’ observational skills are inaccurate and inconsistent, then the CMAs will be unable to accurately evaluate a research project. Thus, this thesis proposes a preliminary yet important initial LMA Effort validation task by asking CMAs to identify eight movement qualities in movement sequences (see Chapter 5, section 5.2). The results are used to create a groundtruthing for the study in this thesis (see Chapter 6, section 6.2). However, this LMA Effort validation is a preliminary evaluation that aims to test only the eight Basic-Effort-Actions in postural effortful actions\(^\text{11}\) (i.e., whole body movement), not gestural actions of one body part or free movement. This LMA validation aims to validate LMA Effort framework and contributes to the research literature by generating results and discussions about the reliability and validity of using CMAs’ expertise to evaluate research projects. However, the validation process can be further explored by consulting with CMAs to define the evaluation goal, task, and study design process.

### 1.5.4. A Set of Design Heuristics for Abstract Visual Representation of Movement Quality

Finally, this thesis provides a set of design heuristics comprised of eight design guidelines for representing eight movement qualities in abstract expressive animation or visualization. This contributes to the LMA Effort and visualization research domains because this guideline can be applied and further explored in various areas, such as visual communication design, abstract animation, and movement analytics (see Chapter 7, section 7.5).

### 1.6. Scope and Limitations

This thesis presents an artistic visualization system that generates visual representations of movement quality derived from Laban Movement Analysis (LMA)

\(^{11}\) See more information about the eight BEAs in the glossary section.
Effort theory. It is important to note that this thesis is limited to visualizing eight movement qualities or the eight Basic-Effort-Actions characterized by Effort Factors\(^{12}\) in postural effortful actions (whole body movement) rather than gestural actions (movement of a single body part). LMA Effort can be used to describe the qualities of both types of actions. For instance, reaching for a glass of water to take a drink with Direct Space, Strong Weight, and Sudden Time qualities (i.e., Punch Effort quality) is different from moving an arm downwards, left, and back with Direct Space, Strong Weight, and Sudden Time qualities (i.e., Punch Effort quality). This example illustrates two different aspects of Punch quality. The limitation of thesis focus to postural effortful actions is because the movement quality recognition system (EffortDetect) used in this research was trained to classify the eight Basic-Effort-Actions from postural effortful actions (see Chapter 4, section 4.2).

1.7. Outline of Thesis Chapters

The rest of this thesis is organized into the following chapters:

Chapter 2 details the conceptual framework and theoretical foundation that help to situate this thesis within the domain of human movement visualization. To review the research context, I begin by describing the historical background of human movement study, computational movement models, and examples of movement visualization research projects. I describe human movement visualization within the artistic visualization domain and identify the characteristics that distinguish this research domain from other contemporary visualization disciplines. I then identify a research gap for articulating how LMA can be used as a design resource for visualizing movement quality.

Chapter 3 describes different research methodologies used in artistic human movement visualization research. The chapter begins with the notion of practice-based arts research, wherein the designing, developing, and art-making of artefacts are the primary activities in the research process. I present a model of interaction design

\(^{12}\) Space Effort Factor (Direct or Indirect), Weight Effort Factor (Strong or Light), and Time Effort Factor (Sudden or Sustained).
research and a model of three design roles in information visualization research, used as a strategy for my visualization design process. I also describe the visualization evaluation method, called evaluating communication through visualization, and the analytical method used in this thesis.

Chapter 4 presents the design process for visualizing movement quality and the creation of three versions of movement quality visualization systems: EMVIZ (L), EMVIZ (Sketch), and EMVIZ (Motion Agent), as well as system usage.

Chapter 5 describes the evaluation methodology, validity, and reliability of this thesis. This includes methods for evaluating communication through visualization, participant selection, study procedures and conditions, data collection, and the data analysis process.

Chapter 6 presents evaluation results (i.e., descriptive and inferential statistic) and detailed feedback from the study.

Chapter 7 brings high-level analysis and discussion to the EMVIZ systems evaluation by describing the unit of analysis, levels of analysis, and comparative analysis procedures used to criticize, analyze, and compare the design strategies of the three EMVIZ systems. To reveal the best set of design criteria for communicating expressive movement qualities, the comparative analysis process evaluates the strengths and weaknesses of the three design strategies and proposes the best set of design guidelines for visualizing movement quality.

Chapter 8 discusses and summarizes the thesis and its conclusions, and provides suggestions for future work.

13 A design model describing three different research strategies in Human Computer Interaction (HCI) proposed by Daniel Fallman, see: Chapter 3, section 3.2.1
14 A visualization design model, adapted from Daniel Fallman’s model of interaction design research, that describes three different roles of visualization design in information visualization research, see: Chapter 3, section 3.2.2
15 An information visualization evaluation method, derived from a comprehensive review of over 800 information visualization papers, described by Lam et al., 2011, see: Chapter 3, section 3.3.
Chapter 2.

Literature Review

This chapter reviews, summarizes, and discusses the theoretical background of two main disciplines (i.e., [a] human movement study in art, design, and computation, and [b] artistic visualization) that assist in framing research in the area of artistic human movement visualization. First, the “human movement study in art, design, and computation” section covers three main areas: (1) the historical background of human movement study in fine art; (2) a brief history of movement theory; and (3) examples of human movement visualization projects. Second, the “artistic visualization” section also covers three main areas: (1) the state of the art of visualization research; (2) several concepts that define characteristics of artistic visualization (i.e., framing artistic visualization); and (3) examples of artistic visualization projects. Figure 2.1 presents the conceptual framework of this thesis.

Figure 2.1. Conceptual framework: artistic human movement visualization
In order to make the connections between practice and theory in human movement study, the chapter begins with a historical background of human movement in fine art, followed by a brief history of non-verbal communication theories, specifically gesture and movement. To identify research possibilities or missing elements in the literature, section two introduces the Laban Movement Analysis (LMA) framework and its use in various computing fields. Section two reviews (a) the state of the art of visualization research in order to determine the similarities and differences among visualization domains (e.g., information visualization, scientific visualization, and data visualization); and (b) several concepts or theoretical models (e.g., sublimity, computational aesthetics, and aesthetics of governance) that describe significant features of artistic visualization. To establish this thesis within an artistic visualization domain, section two then analyzes and synthesizes these concepts/theoretical models to identify key characteristics of artistic visualization.

Section three reviews various human movement and visualization projects in technological contexts and identifies some research gaps regarding the use of LMA in the visualization domain. Section four presents various examples of artistic visualization. The chapter concludes by addressing the possibility of using LMA as a design resource for (1) visualizing high-level semantic movement information (i.e., movement quality) and (2) using artistic visualization characteristics to frame visualization design direction and establish the work within the artistic visualization domain. Figure 2.2 summarizes the literature review process that frames this thesis’ conceptual framework.

<table>
<thead>
<tr>
<th>Literature Review Domain</th>
<th>Review Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical Literature Review</td>
<td>Visualization</td>
</tr>
<tr>
<td>Human Movement Framework</td>
<td>Research Framework</td>
</tr>
<tr>
<td>The State of the Art of Visualization Research</td>
<td>Various Visualization Domains</td>
</tr>
<tr>
<td>Framing Artistic Visualization</td>
<td>Artistic Visualization Characteristics</td>
</tr>
<tr>
<td>Examples of Artistic Visualization Project</td>
<td>LMA as a Design Resource for Visualizing Movement Quality</td>
</tr>
</tbody>
</table>

**Figure 2.2. Summary of the literature review process**
2.1. Human Movement Study in Art, Design and Computation

This section briefly summarizes (1) the historical background of human movement study in art and design from the ancient Greeks to modern technological contexts, (2) examples of artistic projects related to human movement within digital technology, (3) various concepts or analytical systems developed for recording and analyzing nonverbal communication (i.e., gestures, posture or movement [specifically LMA]), and (4) LMA usage in various computing areas, such as gesture recognition, robotics, and human computer interaction. The section concludes by addressing LMA usage as a design resource in digital technology contexts and as a research area that is rarely directly explored, particularly in the visualization domain.

2.1.1. **Historical Background of Human Movement Study in Fine Art**

Humankind has been engaged with movement since the ancient Egyptian, Greek, and Roman periods. During these times, human movement involved various physical activities, such as gathering food, sports competitions, hunting, music, and dance (Klavora, 2010). These physical activities were recorded in sculptures (i.e., bas-relief or high-relief) or illustrations on utensils. Because of social-cultural changes, human movement study shifted to the interdisciplinary areas in art and science, such as psychology, mathematics, neuroscience, kinesiology, anatomy, and fine and performing arts.

In ancient Greece, the Greek philosopher Aristotle (383-321 BCE) studied animal locomotion and observed human motion patterns in particular activities (Klette & Tee, 2008). During the Renaissance period (14th – 17th century), human anatomy and human or animal motion were studied through sketches or drawings by many artists, such as Leonardo da Vinci, Michelangelo, and Raphael. For instance, da Vinci (1452-1519) studied the principles of motion in the human body through his anatomical studies (e.g., nerves, bones, muscles, and sinews) that concerned the human body’s physical and mechanical properties (Klette and Tee, 2008). Da Vinci also studied causes and effects between human anatomy and motion through comprehensive sketches of several human actions, including running, standing, sitting, thrusting, pulling, and pressing (Veltman, 1992). Da Vinci’s study covered not only relationships between human
anatomy and motion but also the motion patterns of animals (e.g., horses running) or that occurred in nature (e.g., water movement). Figure 2.3 presents da Vinci’s movement studies of humans, animals, and nature.

Figure 2.3. Leonardo da Vinci’s motion study: study of battle on horseback and on foot 1503-04 (left); study of water (right)

Note. Images from Study of battle on horseback and on foot (left) and Study of water (right), by L. Da Vinci, 1504-04, http://www.leonardoda-vinci.org / . Copyright by Leonardo Da Vinci. Used under creative commons license.

During the Baroque period (c. 17th century), many artists explored various painting techniques to convey a sense of dynamism, drama, and emotion through human gesture expression. For instance, in The Supper at Emmaus Painting (Fig. 2.4a), Caravaggio conveyed the intensity of the emotions of Christ through hand and body gestural expression in a dark background colour (Caravaggio, 1601). In The Assumption of the Virgin Mary (Fig. 2.4b), Rubens represented Mary’s dramatic expression through her gestural motion towards a burst of divine light (Rubens, 1620). In Lucretia (Fig. 2.4c), Rembrandt captured the emotional expression of Lucretia, a woman who was forced to suicide and choose between life and honour, through her facial expression, gaze, and bodily gesture (Rembrandt, 1664). In addition to movement study in art, Giovanni Alfonso Borelli discovered how the musculoskeletal system’s levers (i.e., limb movement) caused muscles to develop very large forces during physical activity through

1 Giovanni Borelli is often called “the father of biomechanics”; see: (Klette and Tee, 2008).
his mechanical and physiological studies (e.g., muscle analysis or mathematical discussion of movements like running or jumping) based on Galileo Galilei’s geometrical method (Abernethy, 2013; Klette and Tee, 2008) (Fig. 2.4 d).

Figure 2.4.  (a) The Supper at Emmaus; (b) The Assumption of Mary; (c) Lucretia; (d) De motu animalium


In the late 19th century, Étienne-Jules Marey invented a technological method for capturing human motion and animal locomotion, and transforming them into a sequence of images by decomposing and registering image segments on a single photographic plate (Braun, 1992). This sequential photographic process was named
“chronophotography” by an International Congress of Photography in 1889 (Rossell, 2013). Marey’s human motion and animal locomotion studies (Fig. 2.5a) inspired other practitioners (e.g., Eadweard J. Muybridge, Georges Demenÿ, and Charles-Émile Reynaud) to pursue their own motion study research in other areas. For instance, in *The Horse in Motion*, Eadweard Muybridge created the zoopraxiscope, a tool for displaying a sequence of images, in order to study the motion of a galloping horse (Fig. 2.5b) and see whether all four hooves lifted off of the ground (Braun, 1992). In *Fencer*, Georges Demeny captured the traces of fencer motion and revealed action details and motion patterns that human eyes could not perceive (Fig. 2.5c). Several art movements in the modern art period (e.g., cubism, futurism, and abstract expressionism) were influenced by this technological advancement in photography.

**Figure 2.5.** (a) Bird in Flight; (b) The Horse in Motion; (c) Fencer


Inspired by chronophotography, Modern Art period artworks dealing with human motion focused on representing the human figure in motion and its properties such as body, space, and time. In Cubism, artists explored and depicted multiple viewpoints of the subject in painting by layering the subject from different angles on the canvas.
(Apollinaire and Eimert, 2012). For instance, in *Nude Descending a Staircase No.2* (1912), Marcel Duchamp captured human forms and motion (i.e., stepping down a stairway) seen from a single point of view, abstracted them into lines and visual forms, and represented them in a sequence of an abstract human figure in linear motion (Mink, 2004) (Fig. 2.6 a).

![Image](http://en.wikipedia.org/wiki/File:Duchamp_-_Nude_Descending_a_Staircase.jpg) / Copyright 1912 by Marcel Duchamp. Used under Public domain license. Image (a).

![Image](http://commons.wikimedia.org/wiki/File:%27Unique_Forms_of_Continuity_in_Space%27,_1913_bronze_by_Umberto_Boccioni.jpg) / Copyright 1913 by Umberto Boccioni. Used under the public domain license. Image (b).

![Image](http://www.artstor.org/) / Copyright 2008 by Artists Rights Society (ARS), New York / SIAE Rome. Used under ARTstor Digital Library Noncommercial educational and scholarly uses license.

**Figure 2.6.** (a) Nude Descending a Staircase No.2; (b) Unique Forms of Continuity in Space; (c) Abstract Speed + Sound


In Futurism, artists studied how to convey subject movement through visual abstraction that emphasized motion properties, such as dynamism, speed, energy or power (Gottlieb, 1958). For instance, in *Unique Forms of Continuity in Space* (1913-1914), Umberto Boccioni studied the continuity of motion and created a sculpture that
displayed space fluidity surrounding a human body in motion (Fig. 2.6b). In *Abstract Speed + Sound* (1912), Giacomo Balla’s painting depicted motion and represented the sense of speed or dynamism of racing automobiles (Guggenheim, 2014) (Fig. 2.6c).

In Abstract Expressionism, artists explored different techniques to convey strong emotional or expressive content through gestural expression (MoMA, 2014). For instance, Jackson Pollock invented a dipping technique (i.e., gestural painting) and used it as a way to make the artist’s expression, energy, and motion visible in painting (Fig. 2.7a). In *Untitled* (1970), Willem de Kooning depicted gestural motion by transforming a human figure into abstract visual forms (The Pace Gallery, 2011) (Fig. 2.7b).

![Figure 2.7. (a) Convergence by Jackson Pollock and (b) Woman, Sag Harbor by Willem de Kooning](image)

*Figure 2.7.* (a) *Convergence* by Jackson Pollock and (b) *Woman, Sag Harbor* by Willem de Kooning


Looking at the history of movement or motion study in art, we see that early studies focused on recording human activities using drawing or sketching techniques in order to study human anatomy and its properties. In the Baroque period, the studies tended to explore emotional expression through facial expression and body gesture. In the beginning of the Modern Art period, photographic technology caused motion studies to focus on inventing new techniques for recording and analyzing human motion or animal locomotion. This advancement influenced several modern art movements that
explored different ideas for conveying and re-representing human motion in a new way. In parallel with human movement study in art, several theoretical models were developed to expand knowledge in non-verbal communication, specifically human gesture and movement. In the next section, I summarize some significant theoretical models or frameworks, specifically the Laban Movement Analysis Framework, that were created in parallel with human movement study in artistic practice.

2.1.2. **A Brief History of Human Movement Framework**

Gesture and movement communication have been researched in the field of non-verbal communication by various philosophers or scientists (e.g., Socrates, Cicero, and Quintilian) since ancient times (Austin, 1806). In 1644, John Bulwer published a book, *Chirologia: or the Natural Language of the Hand*, which described the use of hand gestural motions as one channel of communication (Bulwer, 1644). In 1872, Charles Darwin published a book titled *On the Expression of Emotions in Man and Animals*, that described emotional expression in humans and animals observed from different behaviours, bodily gestures, and movement (Darwin, 1872). In 1887, Genevieve Stebbins and François Delsarte published *Delsarte System of Expression*, which introduced new techniques and vocabulary, derived from human action observation, for systematically describing how emotions, attitude, and personality are conveyed and expressed in bodily gesture and posture (Marsella et al., 2006; Stebbins and Delsarte, 1887).

In performing arts or dance, many dance theorists have studied and explored how to record, compose or decompose human movement in dance performances. Inspired by music notation, several movement notations were invented using different representation methods (e.g., words abbreviations, track drawings, stick figures, music notes or abstract symbols), such as Labanotation, Benesh movement notation, Eshkol-Wachman movement notation and Sutton movement writing (Guest, 1998). Among them, one of the most well-known and widely used dance notation is Labanotation, created by Rudolf Laban in the 1920s. Labanotation (or Kinetography) is a system

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Movement notation is a set of symbols or graphics used for describe dance movement. Some researchers believe that it has been invented and used since the ancient Egyptians and Romans. However, the first dance notation book, called Orchesographie, was published in 1588 (See: Guest, 1977, p. 1-2).
composed of various sets of abstract symbols or graphical representations of movement originally used for the archival recording of dances. The system has since been applied to other fields (e.g., anthropology, athletics, psychology, and physiotherapy) to record human bodily motions for further analysis. Figure 2.8 presents some examples of movement notations, including Labanotation.

In 1926, inspired by the Delsarte system, Rudolf Laban published the German book “Choreographie” and introduced a movement theoretical framework—later known as Laban Movement Analysis—to describe his analytical approach used for analyzing and understanding human movement (Laban, 1926/2011). Laban’s book incorporated various symbols from Labanotation with his analytical approach to lay a foundation for human movement analysis.

In 1952, Ray Birdwhistell published Introduction to Kinesics and introduced a theory, inspired by Laban’s theory, used for annotating and interpreting human bodily
motion and gesture using a descriptive linguistics approach (Birdwhistell, 1952). Kinesics focused on nonverbal behaviour and looked at different parts of body motion (e.g., facial expression, hand gesture or foot behaviour) from micro level (personal) to macro level (social).

In 1978, Paul Ekman published a paper called “Facial action coding system: a technique for the measurement of facial movement,” in which he described the measurement of human facial expression based on the movement of individual facial muscles. Ekman observed human facial expressions, recorded them, analyzed how muscle movement was related to facial appearances, and ran an experiment to test his hypothesis, resulting in the classification of movement of individual facial muscles corresponding to emotional expression (2005).

Table 2.1 lists some significant movement theoretical frameworks and studies related to nonverbal communication, specifically movement, gesture, and expression.

**Table 2.1. Theoretical models and studies related to movement, gesture, and expression**

<table>
<thead>
<tr>
<th>Year</th>
<th>Author</th>
<th>Name</th>
<th>Feature</th>
</tr>
</thead>
<tbody>
<tr>
<td>~310 -</td>
<td>-</td>
<td>-</td>
<td>Early physical activities studies, such as gathering food, sports competitions, hunting, music, and dance.</td>
</tr>
<tr>
<td>1558</td>
<td>Thoinot Arbeau</td>
<td>Orchesographie (first musical &amp; dance notation book)</td>
<td>A set of symbols incorporated with text, used for teaching dancers to dance with a partner (with music)</td>
</tr>
<tr>
<td>1664</td>
<td>John Bulwer</td>
<td>Chirologia or Chironnmia</td>
<td>Language of hand gesture</td>
</tr>
<tr>
<td>1872</td>
<td>Charles Darwin</td>
<td>The Expression of the Emotions in Man and Animals</td>
<td>Emotional expression within different behavioral modalities, including body movement</td>
</tr>
<tr>
<td>1887</td>
<td>Genevieve Stebbins &amp; François Delarte</td>
<td>Delsarte’s System of Expression</td>
<td>Emotional expression in body gesture and posture</td>
</tr>
<tr>
<td>1920</td>
<td>Rudolf Laban</td>
<td>Labanotation</td>
<td>A set of abstract symbols or graphical representation of movement, originally used for recording dance performance</td>
</tr>
<tr>
<td>1926</td>
<td>Rudolf Laban</td>
<td>Choreographie (later called Laban Movement Analysis)</td>
<td>A movement theory used for describing, analyzing, and understanding human movement</td>
</tr>
</tbody>
</table>
These examples are just some of the significant theoretical frameworks developed in parallel with human movement study in art since ancient times. However, the most well-known framework, widely used in many fields (e.g., therapy, performing arts, psychology, sport science, perception, and cognition.), is Laban’s Choreographie or Laban Movement Analysis (LMA). In digital technology contexts, LMA has been—and continues to be—widely used in various art and computing research domains. The following sections briefly summarize the LMA framework and review LMA usage in art and computing research domains in order to identify research gaps and the need for further contributions in relevant literature.

### 2.1.2.1. Laban Movement Analysis Framework

Laban Movement Analysis (LMA) is an analytical and embodied system for understanding human movement based on Rudolf Laban’s work and subsequently expanded by Laban’s student Irmgard Bartenieff (Bartenieff & Lewis 1980). LMA observes, analyzes, and describes movement using four different components: Body, Effort, Shape, and Space (BESS). Taken altogether, these four components comprise a framework for movement analysis (Laban and Lawrence, 1974). Figure 2.9 presents an overview of LMA’s framework.

---

Figure 2.9. Overview of Laban Movement Analysis framework


BODY

The LMA Body component was developed from Laban’s original work by his student Irmgard Bartenieff to describe the basic components of the human body, the body structure, and its physical features. LMA Body addresses four main elements (see Fig. 2.9) with the questions, “Where in the body does movement initiate? What is consistently maintained in the body? Which body parts are moving? How is the body organized? How does movement spread through the body?” (Hackney, 1998). The theory elaborates on the functional concepts of the patterns of total body connectivity⁴, which can be used to fully understand movement at the body level and applied to various activities (e.g., dance warmup, movement therapy, and motor skills training). The theory not only allows practitioners to understand their personal body movement

patterns in everyday life, but also helps them to use this fundamental knowledge as reference when observing other bodily motions.

**EFFORT**

The LMA Effort component describes the qualitative aspect of the movement or the inner impulse from which movement originates, such as a movement sensation, thought, feeling or emotion (Maletic, 2005). In contemporary dance, this qualitative aspect is referred to as “movement quality” or the characteristics in which the movement is executed (Alaoui et al., 2012). LMA Effort classifies and analyzes movement quality based on four main factors: Space, Weight, Time, and Flow. Each factor is a continuum bounded by two extreme elements (i.e., indulging and fighting), called Effort elements or Effort qualities (Hackney, 1998; Laban, 1960; Laban and Lawrence, 1974). Each factor and its Effort element are summarized and described as follows:

- **Space Effort** relates to the mover’s attention to the environment. Space Effort can be Direct when the mover navigates to a specific focused point in the space or it can be Indirect when the mover has no specific target. Space Effort emphasizes the power of thinking where to move in the space (Bradley, 2008; Hackney, 1998; Laban and Lawrence, 1974; Maletic, 2005).

- **Weight Effort** expresses the mover’s intention in terms of how the body weight has an impact on the environment. Weight Effort can be Strong when the mover exerts a sense of forcefulness in the movement or it can be Light when the mover uses a small amount of power to pull on gravity. Weight Effort emphasizes personal intention and the power of sensing to activate passive or active weight (Bradley, 2008; Hackney, 1998; Laban and Lawrence, 1974; Maletic, 2005).

- **Time** refers to the mover’s decision-making in changing temporal activity. Time Effort can be Sudden or Sustained, depending on the mover’s attitude towards acceleration or deceleration. Time Effort emphasizes the mover’s intuition regarding movement rhythm (Bradley, 2008; Hackney, 1998; Laban and Lawrence, 1974; Maletic, 2005).

- **Flow Effort** refers to movement progression or continuity that appears along with other Effort elements, and it can be Bound Flow or Free Flow. Bound Flow refers to ongoing movement that is determined or controlled by the mover, while Free Flow is Bound Flow’s diametric opposite (i.e., more relaxed and related to feeling). Thus Flow Effort emphasizes feeling—whether the mover feels they desire bound or free movement progression (Bradley, 2008; Hackney, 1998; Laban and Lawrence, 1974; Maletic, 2005).

Table 2.2 summarizes the LMA Effort components comprised of four Effort factors and their qualities.
Table 2.2. LMA factors and their qualities

<table>
<thead>
<tr>
<th>EFFORT FACTORS</th>
<th>EFFORT ELEMENTS</th>
<th>Mover’s inner participation</th>
<th>Power of</th>
</tr>
</thead>
<tbody>
<tr>
<td>Space</td>
<td>Indulging</td>
<td>Fighting</td>
<td>Attention</td>
</tr>
<tr>
<td>Weight</td>
<td>Light</td>
<td>Strong</td>
<td>Intention</td>
</tr>
<tr>
<td>Time</td>
<td>Sustained</td>
<td>Sudden</td>
<td>Decision</td>
</tr>
<tr>
<td>Flow</td>
<td>Free</td>
<td>Bound</td>
<td>Progress/ Continuity</td>
</tr>
</tbody>
</table>

In reality, Effort factors and their elements are often expressed and observed in combination, not in isolation, because at least two Effort Factors are always expressed and observed in movement. The combination of two Effort Factors creates what Laban identified as “incomplete Efforts,” called States, while the combination of three Effort Factors creates the expressive movement called Drives (Fig. 2.9). In total, there are six States (i.e., Awake, Remote, Stable, Dream, Rhythm, and Mobile) and four Drives (i.e., Action, Passion, Spell, and Vision). This thesis only covers Action Drives, which describe eight movement qualities called the “Eight Basic-Effort-Actions” (see Chapter 4, section 4.1).

SHAPE

The LMA Shape component describes the relationships between a mover’s body and the environment based on four main elements: basic forms of shape; shape flow support; mode of shape change; and shape qualities (Hackney, 1998). First, basic forms of shape describes shapes or forms that the body could make, such as linear, flat or round. Second, shape flow support describes how the mover’s breathing process (i.e., growing and shrinking) changes the body’s form. Third, mode of shape change describes three types of the mover’s inner attitude that influences the changing of the body’s form (i.e., Shape Flow; Directional Movement; and Carving). Fourth, shape qualities provide more information on the process of shifting body shape regarding the mover’s breathing process, which describes the direction of shape changing.

SPACE

The LMA Space component describes the relationships between human movement and the space surrounding the body using three main concepts: Kinesphere, Spatial Pulls, and Dimensions. First, the Kinesphere concept describes the mover’s own
personal space (i.e., from near the body to far-reaching space) and the movement initiation within the mover’s Kinesphere that can psychologically affect the audience (Hackney, 1998). Second, Spatial Pulls describes the direction of the mover’s movement in the space and how the mover’s body organizes, connects, and creates the pathway for the movement. Third, the Dimensions concept describes movement directions within the Kinesphere based on a 3D coordinate system: horizontal, vertical, and sagittal. When the mover’s pose reaches the extremes of far-reaching space in the Kinesphere for each dimension, it creates two-dimensional surfaces or planes for horizontal, vertical, and sagittal dimensions (see Fig. 2.9). Within this structure, the mover’s movement can reveal five geometrical shapes (i.e., octahedron, icosahedron, cube, tetrahedron, and dodecahedron) that Laban called “Crystalline forms.”

2.1.2.2. LMA Utilization in Computing

In computing research areas, the application of human movement and LMA to digital technology has been extensively researched. For instance, ACM Guide to Computing Literature keyword searches for the terms Laban Movement Analysis, Laban, Laban Effort, and movement qualities from publication years 1999 to 2014 yielded 139 publication results, while 77 publications\(^5\) used LMA in their project design process. Figure 2.10 shows the increasing LMA utilization in various research fields (e.g., robotics, gesture recognition in multimedia systems, and interaction design) from 1999 to 2014.

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\(^5\) 139 publications were individually reviewed and 77 were selected according to LMA usage described in the design process or the main body of the paper (obtained on 28\(^{th}\) July 2014).


Table 2.3. Examples of LMA usage in various computing contexts

<table>
<thead>
<tr>
<th>Context</th>
<th>Author</th>
<th>Component</th>
<th>Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Character Animation</td>
<td>(Badler et al., 1999)</td>
<td>Effort</td>
<td>An animation framework for expressive movement animation</td>
</tr>
<tr>
<td></td>
<td>(Bishko, 2007; J. Kundert-Gibbs and K. Kundert-Gibbs, 2009)</td>
<td>Effort</td>
<td>The movement vocabulary for teaching animators</td>
</tr>
<tr>
<td></td>
<td>(Chi et al., 2000)</td>
<td>Effort &amp; Shape</td>
<td>A technique to create more natural and expressive character animation</td>
</tr>
<tr>
<td>Computer Aided Choreography</td>
<td>(Calvert et al., 2005)</td>
<td>Body, Shape, Space</td>
<td>A 3D animation software for exploring and experimenting with different ideas in dance performance</td>
</tr>
<tr>
<td></td>
<td>(Carlson et al., 2011a)</td>
<td>Effort &amp; Space</td>
<td>A movement generation system for contemporary choreography</td>
</tr>
<tr>
<td>Game Design</td>
<td>(Barakova and Lourens, 2010)</td>
<td>Effort</td>
<td>A design framework for social games with robots</td>
</tr>
<tr>
<td></td>
<td>(Zacharatos et al., 2013)</td>
<td>Effort</td>
<td>An approach to classifying emotion from body movement in a game play scenario</td>
</tr>
<tr>
<td>HCI &amp; Interaction Design &amp; Interactive Art</td>
<td>(Alaoui et al., 2012)</td>
<td>Effort</td>
<td>A design movement qualities-based interaction</td>
</tr>
<tr>
<td></td>
<td>(Françoise et al., 2014)</td>
<td>Effort</td>
<td>A sonic feedback interactive art system</td>
</tr>
<tr>
<td></td>
<td>(Mentis and Johansson, 2013)</td>
<td>Effort</td>
<td>A study of how movement qualities are perceived and experienced by users</td>
</tr>
<tr>
<td></td>
<td>(Loke and Robertson, 2010a; Loke et al., 2007)</td>
<td>Effort, Shape, Labannotation</td>
<td>A new way to work with moving bodies in interaction design</td>
</tr>
</tbody>
</table>

Figure 2.10. Keyword search result in ACM Guide to Computing Literature for “Laban Movement Analysis” from 1999-2014

Note. This result shows only the papers that used LMA in their design process, not those that only cited LMA in their literature review section.

Table 2.3 lists some examples of LMA application and the project features from various computing contexts.
### Context | Author | Component | Features |
--- | --- | --- | --- |
**Human Gesture Recognition and Expressive Gesture in Multimedia Systems** | (Alaoui et al., 2014) | Effort & Shape | A multimodal system for capturing and representing movement qualities |
| (Aristidou and Chrysanthou, 2013) | Effort | A mathematical model for distinguishing emotional states from various parts of bodily motions |
| (Camurri et al., 1999, 2004, 2009; Volpe, 2003) | Effort & Shape | A computational technique for real-time expressive gesture analysis, synthesis, and classification |
| (Hachimura et al., 2005) | Effort & Shape | A computational technique for extracting LMA features from motion capture data |
| (Pietrowicz et al., 2010) | Effort | An accelerometer-based computational model for classifying movement quality |
| (Swaminathan et al., 2009) | Effort | A computational model for identifying LMA shape qualities from motion capture data using a Bayesian fusion approach |
**Robotics** | (Masuda et al., 2009) | Effort | An LMA computation feature for extracting bodily expression or emotions from robot movement |
| (Nakata et al., 2002) | Effort | An LMA computation model and design guideline for robotic body expression |
| (Rett et al., 2010) | Effort, Space | A computational model used in human-machine interaction (for robot) using a Bayesian reasoning approach |
| (Sharma et al., 2013) | Effort | A flying robot that communicates emotion through its locomotion path and how robotic motions influence the viewer’s perception |
**Visual Language** | (Deray, 2007) | Effort | A design visual language framework and application for analyzing interactions between patients and practitioners in healthcare |
**Visualization** | (Carlson et al., 2011b) | Effort | An information visualization system that visualizes choreographic information in dance performances |
| (Alemi et al., 2014) | Effort | A visual analytic system that visualizes movement quality data (i.e., Effort) captured from motion capture system |

Note. These 33 publications are examples of LMA usage in different research contexts. All publications are obtained from various journal articles and databases, such as the ACM digital library, IEEE Xplore, Springer Link, and Science Direct.

In computer animation, Badler et al. (1999) incorporated movement observation and cognitive psychology with LMA Effort to create an animation framework for expressive movement in animation. Bishko (2007) and J. Kundert-Gibbs and K. Kundert-
Gibbs (2009) used LMA Effort to provide movement vocabulary and teach the animator how to observe and create more natural movements in character animation. Chi et al. (2000) used LMA Effort and Shape qualities to create a computational model for a 3D character animation system that allowed the user to specify Effort and Shape parameters for modifying the movement of different body parts instead of relying on linear interpolation between two key poses. This strategy allowed users to create more natural and expressive movements in character animation.

In computer-aided choreography, Calvert et al. (2005) applied the LMA framework to a 3D animation tool that allowed users to explore different ways to expressively combine various dance movements and experiment with different ideas before rehearsing them with live dancers. Carlson et al. (2011a) incorporated and used LMA Effort and the Space Dimensions concept with genetic algorithm to create a system that generated movements for contemporary choreography.

In game design, Barakova and Lourens (2010) applied LMA Effort as an underlying theoretical model to create a design framework for expressing and interpreting emotional movements in social games with robots. Zacharatos et al. (2013) used LMA Effort to classify and recognize emotion from body movement in a game play scenario.

In HCI, interaction design, and interactive art domain, Schiphorst (2005, 2008, 2009) and Schiphorst and Seo (2011) incorporated LMA Effort with somaesthetics6 to provide a critical study of body experience, a design strategy for embodied practices, and the design of interaction aesthetic in a tangible network interactive installation and wearable art. Loke et al. (2007) used LMA and Labanotation in their movement observation process to describe the interaction between player movement and spatial environment in game. Loke and Robertson, (2010b) used Labanotation as well as LMA Effort and Shape to analyze and describe movement qualities and the spatial shaping of the body in various case studies in order to explore new ways to work with a moving body in interaction design. Alaoui et al. (2012) created movement qualities based

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6 Shusterman (2013) defines somaesthetics as “an interdisciplinary research project devoted to the critical study and meliorative cultivation of the experience and use of the living body (or soma) as a site of sensory appreciation (aesthesis) and creative self-stylization.” See: Shusterman, R. (2013). Somaesthetics. The Encyclopedia of Human-Computer Interaction, 2nd Ed. Retrieved from /encyclopedia/somaesthetics.html
interaction and applied this technique to art installation in order to understand user experience and the benefits of this technique. Mentis and Johansson (2013) explored how movement qualities are perceived and experienced by users through an interactive dance performance. Françoise et al. (2014) created an interactive sonification system for exploring the use of sonic feedback along with LMA Effort factors in dance pedagogy.

In human gesture recognition and expressive gesture in multimedia systems, Camurri et al. (1999) used the theory of Effort and Shape to develop a computational technique for extracting human gesture or dance performance information. Volpe (2003) and Camurri et al. (2004) used LMA Effort (Space) as a theoretical framework for creating multimedia software for real-time expressive gesture analysis and synthesis. Hachimura et al. (2005) proposed a computational technique for extracting LMA features from motion capture data. Camurri et al. (2009) demonstrated how LMA Effort (Space & Time) was used in computational technique to classify expressive hand gesture in tangible acoustic interfaces. Pietrowicz et al. (2010) used LMA Effort as the theoretical model to create an accelerometer-based computational model for movement quality classification. Swaminathan et al. (2009) implemented the LMA computational model to identify LMA Shape qualities from motion capture data using a Bayesian approach. Aristidou and Chrysanthou (2013) used LMA Effort as the underlying theoretical model to implement a mathematical model for distinguishing emotional states from various bodily motions. Alaoui et al. (2014) incorporated LMA Effort and Shape in the analysis and synthesis process of a multimodal system for capturing and representing movement qualities.

In robotics, Nakata et al. (2002) applied LMA Effort to create a computational model and design guideline for basic robotic bodily expression, such as joy, anger, grief, and pleasure. Masuda et al. (2009) presented the use of LMA features to implement computation for extracting bodily expression or emotions from robot movement. Rett et al. (2010) incorporated LMA Effort and Space with a Bayesian reasoning approach to implement a computational model for human-machine interaction and demonstrate computational usage through the development of a social robot. Sharma et al. (2013) applied LMA Effort with computation to design a flying robot that communicated emotion through its locomotion path. They described how robotic motions influence the viewer’s perception and proposed a design guideline for applying LMA Effort to a flying robot.
In visual language, Deray (2007) used LMA Effort as a source to design a visual language framework and a computer application for analyzing interactions between patients and practitioners in the healthcare domain. In the visualization domain, Carlson et al. (2011b) used LMA Effort as an analytical factor for analyzing and visualizing choreographic information in dance performances. Alemi et al. (2014) visualized motion features of movement quality data captured from motion capture systems.

In these examples, LMA was utilized as a referenced theoretical model and applied in the project design process to create meaningful human movement applications. Effort is the most utilized LMA component across many research areas. However, there are few contributions in exploring how LMA Effort and movement expertise can be modified and adapted to the design and application of more richly articulated human movement knowledge within the visualization domain. In the next section, I present examples of human movement and visualization projects and propose how LMA Effort can be utilized and extended to human movement knowledge within the visualization domain.

### 2.1.3. The Examples of Human Movement Visualization Project

Table 2.4 summarizes and lists some examples of human movement visualization projects and their features.

<table>
<thead>
<tr>
<th>Author</th>
<th>Project Name</th>
<th>Type of Work</th>
<th>Goal</th>
<th>Data</th>
<th>Theory / Model</th>
<th>Tool / Technique</th>
<th>Data Mapping</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alemi et al. (2014)</td>
<td>Mova</td>
<td>Web Based Analytical Application</td>
<td>To extract and represent human movement features (LMA Effort) for further analysis</td>
<td>Motion Capture Data</td>
<td>N/A</td>
<td>Javascript &amp; JQuery</td>
<td>Direct</td>
</tr>
<tr>
<td>Carlson et al. (2011b)</td>
<td>ActionPlot</td>
<td>Screen Based Analytical Application</td>
<td>To understand choreographic structures in different contemporary dance works</td>
<td>Time, Effort, Gaze, Tempo, Body Balance, Number of Dancers</td>
<td>LMA &amp; Choreographic Elements</td>
<td>Java Processing Software</td>
<td>Interpretive</td>
</tr>
<tr>
<td>Feng et al. (2014); Feng (2014)</td>
<td>Motionscape</td>
<td>Screen Based Experimental Affective Motion Application</td>
<td>To understand how motion properties can create or elicit different affective impressions</td>
<td>User-generated motion properties, such as direction, path curvature, speed or shape</td>
<td>Motion perception theory</td>
<td>Unity 3D</td>
<td>None</td>
</tr>
<tr>
<td>Author</td>
<td>Project Name</td>
<td>Type of Work</td>
<td>Goal</td>
<td>Data</td>
<td>Theory / Model</td>
<td>Tool / Technique</td>
<td>Data Mapping</td>
</tr>
<tr>
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<td>---------------------------------------------</td>
<td>-------------------------------------------</td>
<td>--------------</td>
</tr>
<tr>
<td>Franke and Kiefer (2012)</td>
<td>Unnamed Sound Sculpture</td>
<td>Screen-Based Artwork</td>
<td>To create a sound sculpture from musical piece form of dancer movement</td>
<td>3D Point Cloud (3D volume)</td>
<td>N/A</td>
<td>Microsoft Kinect; 3D Studio Max</td>
<td>Direct &amp; Interpretive</td>
</tr>
<tr>
<td>Gutknecht et al. (2008)</td>
<td>Expressive Animation in the Interactive Performance</td>
<td>Interactive Dance Performance</td>
<td>To abstract and represent expressive emotion extracted from Butoh dance performance</td>
<td>Motion attributes (e.g., intensity, direction, and flow)</td>
<td>Russell’s circumplex model of affect; HMM Model</td>
<td>Wearable sensors + Bluetooth; Network computers</td>
<td>Direct &amp; Interpretive</td>
</tr>
<tr>
<td>Hilpoltsteiner (2005)</td>
<td>Recreating Movement</td>
<td>Screen-Based Application</td>
<td>To visualize movement in film sequences three-dimensionally</td>
<td>Video Footage</td>
<td>Basic Animation &amp; Film Theory</td>
<td>Adobe Shockwave; Slit-scan</td>
<td>None</td>
</tr>
<tr>
<td>Hoekendijk (2011)</td>
<td>Human Sculpture</td>
<td>2D Print Artwork &amp; Interactive installation</td>
<td>To reveal impressions of human movement and the space surrounding the body from different angles</td>
<td>Video Footage</td>
<td>N/A</td>
<td>Java Processing Software</td>
<td>None</td>
</tr>
<tr>
<td>Ip et al. (2002)</td>
<td>Body Brush</td>
<td>Interactive Artwork</td>
<td>To study the relationships between human body movement, gesture, and the visual art language</td>
<td>Motion Capture Data</td>
<td>N/A</td>
<td>IR Cameras; None Computer vision</td>
<td>None</td>
</tr>
<tr>
<td>JL Design (2013)</td>
<td>CCTV9 IDENT (Couples, Martial Arts, Dancers, Family)</td>
<td>Commercial Animation</td>
<td>To visualize a moment in time in a form of three-dimensional moving sculptures</td>
<td>Motion Capture Data</td>
<td>N/A</td>
<td>3D Software</td>
<td>Direct &amp; Interpretive</td>
</tr>
<tr>
<td>Latulipe and Huskey (2008)</td>
<td>Dance.Draw</td>
<td>Interactive Dance Performance</td>
<td>To explore the concept of exquisite interaction in which collaboration between dancers were used to control and generate visual artifacts</td>
<td>USB Mouse Spatial data (X, Y position)</td>
<td>N/A</td>
<td>Multiple wireless gyroscopic USB mouses</td>
<td>Direct &amp; Interpretive</td>
</tr>
<tr>
<td>Lagan and Maher (2011)</td>
<td>Choros</td>
<td>Experimental Film (artwork)</td>
<td>To revisit old technical innovations and combine with advancements in digital technology in order to visualize movement of body, space, and time</td>
<td>Sequences of Image</td>
<td>Chronophotography</td>
<td>Film/ Digital Compositing</td>
<td>None</td>
</tr>
<tr>
<td>Lockyer &amp; Bartram (2012)</td>
<td>aMotion Toolkit</td>
<td>Screen-Based Experimental Motion texture Application</td>
<td>To understand how motion properties can create or elicit different affective impressions and how artists and designers apply aMotion Toolkit in their practice</td>
<td>User-generated motion properties, such as direction, path curvature, speed or shape</td>
<td>Motion perception theory</td>
<td>Unity 3D</td>
<td>None</td>
</tr>
<tr>
<td>Author</td>
<td>Project Name</td>
<td>Type of Work</td>
<td>Goal</td>
<td>Data</td>
<td>Theory / Model</td>
<td>Tool / Technique</td>
<td>Data Mapping⁹</td>
</tr>
<tr>
<td>---------------------------</td>
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<td>----------------------------------------------------------------------</td>
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<td>--------------------------</td>
<td>----------------</td>
</tr>
<tr>
<td>Maruyama (2012)</td>
<td>Nude</td>
<td>Photography (Artwork)</td>
<td>To capture the beauty of human body’s figure and its motion</td>
<td>10,000 Individual Photographs</td>
<td>N/A</td>
<td>Camera; Long exposure technique</td>
<td>None</td>
</tr>
<tr>
<td>OpenEnded Group (2001)⁸</td>
<td>Loops</td>
<td>Screen-Based Artwork</td>
<td>To artistically visualize Merce Cunningham’s gesture movement of hands and fingers</td>
<td>Motion Capture Data</td>
<td>N/A</td>
<td>Custom Software</td>
<td>N/A</td>
</tr>
<tr>
<td>Palazzi and Shaw (2009)⁹</td>
<td>Synchronous Objects for One Flat Thing</td>
<td>Screen-Based Artwork</td>
<td>To unfold and visualize William Forsythe’s Choreographic Structures</td>
<td>Spatial Data (X, Y, Z) Attribute Data (movement material, cueing, alignment)</td>
<td>Choreographic principles of counter-point (William Forsythe)</td>
<td>Computer Vision; Generative Software; 3D Software; etc.</td>
<td>Direct &amp; Interpretive</td>
</tr>
<tr>
<td>Perret (2009)</td>
<td>BodyCloud</td>
<td>3D sculpture (Artwork)</td>
<td>To capture aesthetic of human physical expression by transforming intangible form of human movement into a live physical aesthetic object</td>
<td>3D Point Cloud Materialization of body movements</td>
<td>N/A</td>
<td>Motion Capture/3D Studio Max</td>
<td>Direct</td>
</tr>
<tr>
<td>Quayola and Akten (2012)</td>
<td>Forms</td>
<td>Audio-visual Installation (Artwork)</td>
<td>To explore extrapolation techniques for sculpting abstract forms between the body and its surroundings</td>
<td>Tracking information (X, Y, Z) extracted from video footage</td>
<td>Chrono-photography &amp; cubist art movement</td>
<td>Houdini (3D)</td>
<td>Direct &amp; Interpretive</td>
</tr>
<tr>
<td>Shan et al. (2010)</td>
<td>Untitled</td>
<td>Screen-Based Application</td>
<td>To analyze and reveal movement signature</td>
<td>Motion Capture Data</td>
<td>N/A</td>
<td>Motion Capture System</td>
<td>Direct</td>
</tr>
<tr>
<td>The Forsythe Company (2010)</td>
<td>MotionBank</td>
<td>Collection of various projects (i.e., screen-based application, dance score or performance)</td>
<td>To create online digital scores in collaboration of various choreographers Use data from score to create new form of visualization</td>
<td>Body position and orientation of body joints in a 3D coordinate system</td>
<td>Various (depends on each choreographer)</td>
<td>Video Camera &amp; Microsoft Kinect</td>
<td>Direct &amp; Interpretive</td>
</tr>
<tr>
<td>Universal Everything (2012)</td>
<td>Made by Humans</td>
<td>Screen-Based Visual &amp; Sound Installation</td>
<td>N/A</td>
<td>Motion Capture Data</td>
<td>N/A</td>
<td>Motion Capture &amp; 3D Software</td>
<td>Direct &amp; Interpretive</td>
</tr>
<tr>
<td>Universal Everything (2013)</td>
<td>Presence</td>
<td>Screen-Based Visual &amp; Sound Installation</td>
<td>To explore the intersection of human movement and computer coding (gestural drawing and choreography)</td>
<td>Motion Capture Data</td>
<td>N/A</td>
<td>Motion Capture &amp; Custom Software</td>
<td>Direct &amp; Interpretive</td>
</tr>
</tbody>
</table>
From these examples, human movement and visualization projects can be categorized into four main groups, described as follows:

Group 1: human movement and visualization projects that focus on enabling users to interact, control, and generate visualizations using movement properties (e.g., spatial dimensions, trajectory, direction, speed, and acceleration). For instance, Expressive Animation in a Butoh dance (Gutknecht et al., 2008), Body-Brush (Ip et al., 2002), and Dance.Draw (Latulipe and Huskey, 2008). Figure 2.11 presents an example of gestural or movement control visualization.

![Figure 2.11. An example of gestural or movement control visualization](http://dancedraw.uncc.edu/DanceDraw/Photos_Mus_Musculus.html)

Group 2: human movement and visualization projects that use tool and technique to capture traces of movement and the aesthetic of human bodily motion (i.e., freeze body, space, and time). For instance, Recreating Movement (Hilpoltsteiner, 2005);
Human Sculpture (Hoekendijk, 2011), Choros (Lagan and Maher, 2011), Nude (Maruyama, 2012), BodyCloud (Perret, 2009), Untitled (Shan et al., 2010), and Dancers in Motion (Wadman, 2012). Figure 2.12 presents an example of the BodyCloud visualization project, which aims to capture the aesthetic of human physical expression. BodyCloud abstracts and transforms intangible human movement into a physical aesthetic object and offers new ways for the viewer to experience frozen trace forms of body motion and time surrounding the human body.

Figure 2.12. BodyCloud: visualization that aims to capture the aesthetic of human physical expression


Group 3: human movement and visualization projects that use motion capture systems to capture spatial information (i.e., the position and orientation of body joints in a 3D coordinate system), and then abstract and re-present this set of information in an abstract visual form that is still recognizable to the viewer. For instance, CTTV9 IDENT (JL Design, 2013), Loops (OpenEndedGroup, 2001), Forms (Quayola and Akten, 2012), Made by Human (Universal Everything, 2012), and Presence (Universal Everything, 2013). Figure 2.13 presents an example of the Forms visualization, which represents human movement information in abstract visual form.
Group 4: human movement visualization projects that focus on representing the complexity of human movement information or experimenting with motion and perception. These types of information are considered high-level semantic information derived from movement observation, movement analytic process, the study of meaning in human movement or scientific experimentation (e.g., body balance information, movement qualities, counterpoint\(^7\) information, choreographic information or motion perception and affective impressions). For instance, ActionPlot (Carlson et al., 2011b), Synchronous Objects (Forsythe, 2009; Palazzi and Shaw, 2009), and MotionBank (The Forsythe Company, 2010). Figure 2.14 presents an example of Synchronous Objects visualization, which represents counterpoint information such as the relationships of action between cue giver and cue receiver.

\(^7\) Counterpoint is generally a musical term used to describe an important element of music, such as rhythm, melody, harmony, color or text. However, counterpoint is not only one of the basic elements of music, but also refers to the relationships between more than one independent element happening simultaneously in a piece of music (Schmidt-Jones, 2011). When referring to dance, this concept can be used to describe the relationships between two or more choreographic elements.
In these examples, complex movement information, such as the notion of movement qualities, is still under exploration. Movement qualities are considered high-level semantic information that can be measured or captured from the human body using different tools, methods, technologies, and computations. Movement qualities information can be obtained by exploring the semantics and expressive motion frameworks or LMA Effort.

Figure 2.15 summarizes the literature review of human movement study in the art, design, and computation domains. While LMA has broad application across research fields, this literature review shows that the integration or use of LMA Effort in the visualization field is still being explored. To summarize, there is a research gap for articulating how to use or apply LMA Effort as an underlying model to capture, represent, and map high-level semantic movement information (i.e., movement quality) to a visualization system.
The next section describes the visualization domain’s historical background and reviews several concepts that have contributed to defining the characteristics or criteria of artistic visualization. These characteristics/criteria are used to frame the direction of my research and describe how this thesis’ visualization research differs from other visualization research domains (e.g., data visualization, information visualization, and scientific visualization).
2.2. Artistic Visualization

2.2.1. The State of the Art of Visualization Research

Visualization is a term generally used when referring to making the invisible, visible. The Oxford English Dictionary contains the following definitions for visualization: “(1) The action or fact of visualizing; the power or process of forming a mental picture or vision of something not actually present to the sight; a picture thus formed; and (2) the action or process of rendering visible” (OED, 2012).

Historically, visualization’s roots are drawn from various disciplines, such as cartography, statistics, and astronomy. Around 200 BC, visualization was first used by the ancient Egyptians as a technique for planning the layout of the towns by using the idea of coordinates. Around c. AD 85–165, Claudius Ptolemy used coordinates to map a projection of a spherical earth using latitude and longitude, which later developed into a two-dimensional coordinate system by René Descartes (Friendly, 2008). In the late 17th to early 18th century, the idea of using graphical forms to represent data was developed and established to expand knowledge in statistics and cartography. The most famous examples are the work of William Playfair and Charles Joseph Minard. In Playfair’s work, he used the graphical forms (i.e., line and bar chart) to create a parallel time series chart that displayed labour wages by the week and the price of a quarter of wheat along with the reigns of monarchs displayed on the top (see Fig. 2.16). In Minard’s work, he used a diagram to illustrate the failure of Napoleon’s army during the Russian campaign in 1812 (see Fig. 2.17). To illustrate the Russian campaign, the diagram used the width of a rectangle to represent the size of Napoleon’s army marching across the map to its outward camp (light brown) and their retreat (black). The graph at the bottom showed recorded temperatures during the army’s retreat back to camp. These two examples are considered the early development stage of data visualization, a term often used today to refer to the process of using graphical representation to represent complex data.

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Figure 2.16. The price of a quarter of wheat, and labour wages by the week from 1565 to 1821


Figure 2.17. A diagram of Napoleon’s army during the 1812 Russian campaign


However, modern data visualization was born from three significant developments between 1950 and 1975: the publication of The Future of Data Analysis by John W. Tukey and Semiology of Graphics by Jacques Bertin; the development of
computer processing; and the creation of a high-level computer language called Fortran (Friendly, 2008, p. 39). John W. Tukey, an American mathematician, was known for his invention of many simple and effective graphic displays for data analysis—a branch of statistics—such as box plots, hanging rootograms, and stem-leaf plots. His graphical data analysis techniques were widely used and increased interest in the data visualization field. Jacques Bertin, a French cartographer and theorist, is considered a pioneer of data visualization. Bertin laid the foundations for the visual organization of graphic communication principles or semiotics of graphic sign-system (e.g., chart, graph, map or diagram), which is used to explore and communicate the complexity of data. In the late 1960s, computer mainframes were used at various universities to develop new graphic applications (e.g., statistical applications and high-resolution graphics), which sparked the idea of using computers in the visualization field.

In the last twenty-five years, visualization has become a popular research area because advancements in digital technology produced a large and complex collection of datasets that are difficult to process. Thus, researchers have extensively explored the development of processes, computational algorithms, and applications to generate visual representations for reinforcing human cognition and perception. The foundational period of visualization in academic contexts began in 1990, when the Institute of Electrical and Electronics Engineers (IEEE) held the first visualization conference and published the IEEE Transactions on Visualization and Computer Graphics journal in 1995 (Burkhard, 2005; Polanco and Zartl, 2002). Thus, in the late 20th century, scientific visualization and information visualization became two main streams in the visualization research community. However, they were sometimes referred to interchangeably as “data visualization.”

Information visualization is an interdisciplinary research field related to both computer science and the theory of human perception and cognition. With broad consensus among computer scientists and researchers, the term “information visualization” generally refers to “the use of computer-supported, interactive, visual representations of abstract data in order to amplify cognition” or “the applications that generate representation of possible visual representations for reinforcing human cognition and perception” (Card, 2008, 1999; Tory and Moller, 2004; Ware, 2004). These terms were firmly established and provided by notable researchers in the field, such as Stuart Card, Robert Spence, Jock Mackinlay, and Ben Shneiderman.
Similarly, scientific visualization is a branch of computer science and research in computer graphics, established in 1980 by the US National Science Foundation (NSF), and it typically measures or simulates data representing objects or concepts associated with phenomena from the physical world (McCormick et al., 1987; de Oliveira and Levkowitz, 2003; Tory and Moller, 2004; Wright, 2007). Scientific visualization used to be called “visualization in scientific computing” and is defined as a method of computing and a process of transforming the symbolic into the geometric in order to enable researchers to observe their simulations and computations (McCormick et al., 1987). Scientific visualization offers a method for seeing the unseen, enriches the process of scientific discovery, and fosters profound and unexpected insights (McCormick et al., 1987).

Unlike information visualization and scientific visualization, data visualization has a slightly narrow domain, as Friendly (2009) notes:

Data visualization is the science of visual representation of “data”, defined as information, which has been abstracted in some schematic form, including attributes or variables for the units of information. The field could be taken to subsume the two main focuses: statistical graphics and thematic cartography (Friendly, 2009, p. 2)\(^1^0\).

Along with data, scientific, and information visualizations, there are other significant visualization domains in the research community, such as geovisualization (geographic visualization), visual analytics, and knowledge visualization. Geovisualization is a field of study with roots in cartography, which integrates various approaches from scientific computing, image analysis, information visualization, exploratory data analysis, and geographic information research to provide theory, methods, and tools for the visual exploration, analysis, synthesis, and presentation of geospatial data, such as the characteristics of climate, population density or geographical location (Nöllenburg, 2007, p. 253). Visual analytic is the science of analytical reasoning supported by interactive visual interfaces (Thomas and Cook, 2005), which emerged from such fields as scientific visualization, information visualization, and cognitive science, among others. It integrates methodology from information analytics, geospatial analytics, science of analytics, data mining, information

\(^{10}\) See more information about milestones in the history of thematic cartography, statistical graphics, and data visualization at http://datavis.ca/milestones; http://euclid.psych.yorku.ca/SCS/Gallery/milestone
visualization, knowledge science, human factors, and ergonomics to facilitate communication between humans and computers as well as the decision-making process (Cook et al., 2007; Ham, 2010). Knowledge visualization emerged from information visualization and visual communication. It examines and investigates the use of visual representations to construct and convey complex insights of knowledge and transfer knowledge between at least two people (Burkhard, 2005; Eppler and Burkhard, 2004; Meyer, 2008; Tergan and Keller, 2005).

These main streams of visualization grew many subfields, such as bioinformatics visualization, biomedical visualization, and social media analytics (see Fig. 2.18). In this thesis, I use the term “contemporary visualization” to refer to the main streams and their subfields in the visualization research community.

**Figure 2.18. The main streams and subfields of visualization research**

*Note.* The examples of visualization sub fields were taken from one of the longest-running Information Visualization Conferences; see http://www.graphicslink.co.uk/IV2014/symposia.htm

For review, Table 2.5 summarizes the key characteristics of six main streams of the visualization research domain: data visualization, information visualization, scientific visualization, geovisualization, visual analytics, and knowledge visualization.
<table>
<thead>
<tr>
<th>Characteristics of six main streams of visualization research</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Origin / Root</strong></td>
</tr>
<tr>
<td>Data Visualization</td>
</tr>
<tr>
<td>• Cartography</td>
</tr>
<tr>
<td>• Statistical Graphics</td>
</tr>
<tr>
<td>• Astronomy</td>
</tr>
<tr>
<td>• Computer Graphics</td>
</tr>
<tr>
<td>• Presentation Techniques</td>
</tr>
<tr>
<td>• Cognition</td>
</tr>
<tr>
<td>• Other origins</td>
</tr>
<tr>
<td>Information Visualization</td>
</tr>
<tr>
<td>Emerged from:</td>
</tr>
<tr>
<td>• Human-computer interaction (HCI)</td>
</tr>
<tr>
<td>• Visual communication design</td>
</tr>
<tr>
<td>• Psychology</td>
</tr>
<tr>
<td>• Cognitive science</td>
</tr>
<tr>
<td>• Computer science (Bederson and Shneiderman, 2003)</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Characteristics</td>
</tr>
<tr>
<td>-----------------</td>
</tr>
</tbody>
</table>
| Scientific Visualization | Emerged from the advances of computer technology:  
  - Computer graphics  
  - Image processing  
  - Computer vision  
  - Signal processing  
  - User interface studies (McCormick et al., 1987; Wright, 2007). | Usually related to physical entities or scientific data with an inherent spatial component:  
  - Molecular structure  
  - Human organs  
  - Earth geography  
  - Fluid flow  
  - Velocity of airflow  
  - Three-dimensional medical images (Spence, 2007; Tory and Moller, 2004) | To promote a deeper level of understanding of or gain insight into data by transforming numerical data into a visual representation or organizing the data in a way that permits the brain to understand relationships within huge quantities of data (AICT: University of Alberta, 2006; Earnshaw and Wiseman, 1992). | Offers many benefits to the scientific community at large:  
  - Mathematics  
  - Medical imaging  
  - Diagnostic medicine  
  - Orthopaedic prostheses  
  - Radiation treatment planning  
  - Predicting and preventing natural disaster  
  - Other benefits | Surface rendering, slices, and cross sections, contours and isosurfaces, glyphs, vector fields, streamlines, animation, downsizing, threshold, exteriors and edges or colourmaps (AICT: University of Alberta, 2006). |
| Geovisualization | - Cartography,  
  - Scientific computing,  
  - Information visualization  
  - Exploratory data analysis  
  - Geographic information | Usually related to physical entities, such as  
  - Geospatial data (e.g., a road network from GIS or a geo-referenced satellite image)  
  - Oceans  
  - Land masses  
  - Terrain  
  - Roads  
  - Climate  
  - Population | To provide theory, methods, and tools for exploring, analyzing, synthesizing, and presenting geospatial data (MacEachren & Kraak, 2001 cited from Nöllenburg, 2007, p. 257)  
  OR  
  - To use visual geospatial display to explore data, generate hypotheses, problem-solve, and construct knowledge (Longley, 2005 cited from Nöllenburg, 2007, p. 257) | Offers many benefits to other fields of study, such as archaeology, environmental studies, urban planning, geology, and ecology.  
  - Helps to explore, understand, and communicate geospatial information or spatial phenomena such as climate characteristics  
  - Helps decision-making and knowledge creation  
  - Other benefits (Nöllenburg, 2007) | Multi-resolution modeling (e.g., terrain simulation or terrain texture), texturing and multi-texturing, interactive dynamic 3D maps, dynamic texture generation, and so on (Dykes et al., 2005). |
## Characteristics

<table>
<thead>
<tr>
<th>Origin / Root</th>
<th>Data Types</th>
<th>Goal</th>
<th>Value</th>
<th>Representation Technique</th>
</tr>
</thead>
</table>
| Knowledge Visualization | Social sciences, particularly in:  
  - Learning  
  - Instructional science  
  - Business knowledge management  
  - Communication science (Keller and Tergan, 2005). | Any information that is cognitively processed and integrated into an existing human knowledge structure (Burkhard, 2005). | To improve knowledge transfer among people or in groups  
  To solve problems and improve collaboration among isolated fields of research  
  To transfer insights, experiences, attitudes, values, expectations, perspectives, opinions, and predictions in order to enable someone else to re-construct, remember, and apply these insights correctly (Burkhard, 2005; Eppler and Burkhard, 2004; Keller and Tergan, 2005). | Helps organizing and reorganizing, structuring and restructuring, assessing, evaluating, elaborating, communicating, and (co-)constructing knowledge, and to utilize ideas/thoughts/knowledge about relevant contents and resources (Holly & Dansereau, 1984; Jonassen, Beissner & Yacci, 1993; Tergan, 2003 cited Keller and Tergan, 2005). |

| Visual Analytics | Scientific visualization  
  Information visualization  
  Cognitive science (Thomas & Cook, 2005) | Spatio-temporal data (e.g., tracking moving objects)  
  Geospatial data  
  Network and graph data  
  Big data (i.e., numeric, text-based, and Imaging data)  
  Other data types | To create tools and techniques to support people in synthesizing information and discovering insight from massive, dynamic, unclear, and often conflicting data (Ham, 2010).  
  To make complex information structures more comprehensible, facilitate new insights, and enable knowledge discovery (Aigner et al., 2007). | Offers many benefits to various disciplines, such as medicine & biotechnology, business, security & risk management, environment & climate research, healthcare or any field that needs to analyze, interpret, present, and explore large amounts of complex data  
  Improve knowledge and decision-making | Similar to other visualization domains but has some interactive features:  
  Table, pie chart, line chart, bar chart, area chart, histogram, scatterplot, spectogram, radar chart, data map, treemap, cone tree, hyperbolic tree, information lense, parallel coordinates, box plot, and so on. |

Over the last few years, contemporary visualization was developed by new media art, digital art, and interactive art practice, resulting in a new visualization...
discipline. In this thesis, I use the term "artistic visualization" to refer to this new field. The next section briefly summarizes the artistic visualization field and its characteristics.

2.2.2. Framing Artistic Visualization

In the late 1990s, artistic practice was influenced by the advancement of technological development and digital technology became an essential part of the creative process. Data or digital information has become a raw material for artists, designers, and scientists to experiment and research on how to create new approaches that reveal the structures inherent in the dataset or how to create meaningful visual representation that reflects artistic manifestations. This type of art practice appeared in the historical development of new media art or digital art influenced by the main streams of visualization research. This area is often interchangeably called data art, data visualization art, aesthetic visualization, aesthetic information visualization, visualization art, information art, artistic visualization or art-inspired visualization. Figure 2.19 presents artistic visualization practice and examples of related topics that appeared in parallel with contemporary visualization research.

![Artistic Visualization](image)

Figure 2.19. Examples of related topics of artistic visualization domain

*Note.* The examples were taken from (1) *IEEE VIS Arts Program,* (2) **International Conference Information Visualisation: Visualization, Art, and Design,* and (3) ***Computational Aesthetics in Graphics, Visualization and Imaging* conference; see [http://visap.uic.edu/2014/index.html](http://visap.uic.edu/2014/index.html); [http://www.graphicslink.co.uk/IV2014/VAD.htm](http://www.graphicslink.co.uk/IV2014/VAD.htm); [http://expressive2014.mpi-inf.mpg.de/CAe/Home](http://expressive2014.mpi-inf.mpg.de/CAe/Home)

These examples are very broad and can be generally relevant to art and design practice and computer generated visualization. However, artistic visualization has its
own characteristics that differ from contemporary visualization. To understand the nature of the artistic visualization domain, several artists and researchers have attempted to identify and describe the key characteristics of artistic visualization based on various concepts and ideas drawn from related disciplines (e.g., conceptual art, philosophy or aesthetic). Table 2.6 summarizes and lists some significant attempts to frame and describe the characteristics of artistic visualization.

### Table 2.6. Attempted descriptions of the characteristics of artistic visualization

<table>
<thead>
<tr>
<th>Author</th>
<th>Term used</th>
<th>Discuss Topics</th>
<th>Focus Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fishwick (2006)</td>
<td>Aesthetic Computing</td>
<td>Relationships between aesthetic and computation</td>
<td>-</td>
</tr>
<tr>
<td>Judelman (2004)</td>
<td>Artistic visualization</td>
<td>Conceptual inspiration from algorithm art and artificial life</td>
<td>-</td>
</tr>
<tr>
<td>Kosara (2007)</td>
<td>Artistic visualization</td>
<td>Classification of infovis based on the concept of sublimity</td>
<td>O</td>
</tr>
<tr>
<td>Lau and Moere (2007)</td>
<td>Information aesthetics</td>
<td>The experience of aesthetics, dataset interpretation, data mapping, and interaction</td>
<td>O</td>
</tr>
<tr>
<td>Manovich (2002, 2008)</td>
<td>Data visualization art</td>
<td>Concept of sublimity in data art</td>
<td>O</td>
</tr>
<tr>
<td>Paul (2002, 2008)</td>
<td>Data Art</td>
<td>Historical development of data art</td>
<td>-</td>
</tr>
<tr>
<td>Pousman et al. (2007)</td>
<td>Casual Infovis, Ambient Infovis, Informative art, Artistic Infovis, Data-driven art</td>
<td>Visualization works that have various characteristics beyond the boundary of information visualization</td>
<td>O</td>
</tr>
<tr>
<td>Ramirez (2010)</td>
<td>Information visualization art, Artistic information visualization</td>
<td>Comparison of infovis and artistic visualization based on concepts of function and aesthetic</td>
<td>-</td>
</tr>
<tr>
<td>Sack (2007, 2011)</td>
<td>Aesthetics of information visualization</td>
<td>Infovis undertaken as artistic research with an aesthetic concern (focus specifically on concept of the work)</td>
<td>-</td>
</tr>
<tr>
<td>Skog (2006); Skog et al. (2003)</td>
<td>Informative art, Ambient information visualization</td>
<td>Visualization works that integrate into daily lives with emphasis on beautification and clarification of the dataset</td>
<td>-</td>
</tr>
</tbody>
</table>
Christine Paul’s digital art reviewed and surveyed the historical development of data art in digital art practice, a field that uses digital technology in the creative process and has strong connections with Dada, Fluxus, and conceptual art movements (Paul, 2008). Data art appeared in digital art practice where artists used data as the material to manifest their artistic idea and art creation.

Manovich (2002; 2008), a new media theorist, used the concept of data visualization art—drawn from Romantic art—\(^\text{11}\) to understand the nature of data art. Manovich used this concept to argue that data visualization art is anti-sublime because it aims to represent phenomena beyond the scale of human senses (e.g., weather patterns or astronomical objects) in order that they can be perceived by people (Manovich, 2002; 2008). From his perspective, data visualization is a new form of abstraction in which data visualization artists use custom design processes to abstract and represent data in a way that human senses can perceive.

The significant features of data art are the concept and process behind the artistic work that uses data as material for generating new representation, new information, and new meaning (Whitelaw, 2008). For instance, Lisa Javbratt’s web-based work *Infome Imager* transforms web IP address data into pixel color values (new representation) that reveal the complexity of cyberspace structures. Jason Salavon’s *Top Grossing Film of All Time* uses averaging color pixels technique to select the best

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\(^{11}\) Romantic art is the art movement focused on exhibiting new experiences in confronting sublimity such as human emotion and aesthetic in nature (Manovich, 2002).
color representation of each frame and restructure them in a way that reveals changes in film colours and moods (new information). Alex Dragulescu’s *Spam Plants and Spam Architecture* transforms email text (data) into representations of plants and architecture in order to generate new meaning of data (Whitelaw, 2008).

In parallel with digital art practice, Judelman (2004) notes that the growth of the visualization research community attracted more attention from artists, designers, and architects to work on visualization with focus on different techniques used for generating sensory visualization outcomes. To generate meaningful visualizations, many artists and researchers did experimental work using concepts inspired by or borrowed from other disciplines, such as computational complexity theory (e.g., artificial life, cellular automata, and fractals). They integrated these concepts with the visualization design process by experimenting with computer algorithms, visual metaphors or design principles to map data into visual forms. This visualization design approach brings new cross-disciplinary ideas and solutions to the contemporary visualization community, and describes one significant feature (i.e., process) of visualization work aimed at generating sensory outcomes.

Paul Fishwick’s *Aesthetic Computing* examines the relationships between aesthetics and computation from various perspectives, such as art, emotion, metaphor, mathematics, visualization, programming, and interface design. Aesthetic computing is defined as “the application of the theory and practice of art to the field of computing” (Fishwick, 2006, p.6) and it focuses on the impact and effects of aesthetics. Visualization is among many fields where aesthetic computing can be applied to explore a new multidisciplinary approach (i.e., artistic visualization) and expand our knowledge beyond contemporary visualization. The use of aesthetic computing to describe the features of artistic visualization suggests that the artistic goal, process, and outcome are three integral parts of artistic visualization. This is because computing is used as a medium, integrated with art theory and practice, and focused on aesthetic through the whole process of visualization design, that is, not only the outcome (i.e., creative artefact) but the goal and system implementation process as well (Fishwick, 2006, 2007).

Fernanda Viegas and Martin Wattenberg (2007) explicitly described four important characteristics of artistic data visualization: (1) it must be based on actual data rather than visualization metaphors or surface appearance, because it requires mapping between data and image; (2) it must focus on aesthetics based on artistic intent; (3) its goal is to express the artist’s point of view and to persuade or change the way people think; and (4) artistic visualization is work done by an artist with the intention of making art.

Andres Ramirez (2008) describes the differences between traditional information visualization and aesthetic information visualization based on visualization’s function and the aesthetic outcome. From his perspective, the functional information visualization’s goal is to help users to see underlying data. Aesthetic information visualization, on the other hand, is concerned with the attractiveness of data representation or the sensory visualization outcome. Information visualization that is considered art is regularly selected based upon aesthetic or design qualities (Ramirez, 2008). The goal of aesthetic information visualization is not to resolve issues or problems, but to question particular topics and restructure them in a way that reflects the artist’s artistic intention. Thus, an artistic information visualization project has a specific form and artistic goal. Ramirez suggested that artistic information visualization uses visual metaphors that need not be easily decipherable or aesthetically pleasing as long as they reflect the artistic intention or research objective (Ramirez, 2008).

Lau and Moere (2007) proposed the term “information aesthetics” as an independent research area focused on aesthetics to bridge the gaps between information visualization (function-based visualization) and aesthetic visualization. They described and identified the differences between functional information visualization and aesthetic visualization based on the data representation and data mapping process. Data representation of functional information visualization tends to present the patterns hidden inside datasets, while visual cognition and perception psychology theory are often employed in the data-mapping process. The data representation of aesthetic visualization, on the other hand, often focuses on communicating the meaning of data, while data mapping processes are driven by cross-disciplinary inspirations (e.g., mathematics, philosophy or biology) combined with metaphors and art theory. Thus, data representation and the data mapping process are significant features that
differentiate aesthetic-based visualization from function-based visualization (Lau and Moere, 2007; Moere, 2007).

Warren Sack (2007; 2011) provided art history and philosophy contexts for understanding information visualization undertaken as artistic research with an aesthetic concern based on the notion of “aesthetics of governance”—a concept that artists want to reflect in their artworks. Sack essentially suggested that the viewer focuses not only on sensory outcomes but also on the concept behind aesthetic visualization works, in order to appreciate and understand the value of this type of visualization. This idea seems to suggest that a significant trait of aesthetic visualization is the concept behind the work.

Informed by Sack’s (2007; 2011) work, Robert Kosara (2007) presented a classification of several types of information visualization based on the aesthetic criteria of sublimity. This concept focuses on sensory outcome and classifies types of information visualization based on the aesthetic criteria of readability and recognizability. The information visualization work’s outcome can be either utilitarian (i.e., recognizable and readable) or sublime (unrecognizable and unreadable). Kosara used the term “pragmatic visualization” to refer to recognizable and readable visualization and “artistic visualization” or “visualization art” to refer to unrecognizable and unreadable visualization. More precisely, visualization art is information visualization work that presents unique visual forms but does not provide any information or is unreadable, such as music visualization. Here, pragmatic visualization’s goal is to make the data easy to perceive and allow the user to explore, analyze or understand underlying patterns. In contrast, the goal of artistic visualization is to transform the data into something interesting or communicate a concern rather than to represent the data. Kosara identified another type of visualization situated in-between artistic visualization and pragmatic visualization, called “ambient visualization.”¹³ Unlike pragmatic or artistic visualization, ambient visualization is easy to read for those who know how to read but it may not be recognizable for those who do not (Kosara, 2007). Thus, from Kosara’s perspective, the significant characteristics of artistic visualization are the goal or artistic intention and the outcome or visual experience of visualization.

¹³ Ambient visualization is the visualization application that does not reside on a desktop computer’s screen but is present in the environment of the user (Skog et al, 2003).
Skog (2006) and Skog et al. (2003) explored the design process, aesthetic, and usability of ambient information visualization. Skog et al. used the notion of “informative art”—the use of modern artists’ style (e.g., Piet Mondrian and Andy Warhol) to encode information—as an inspiration to develop the visualization design. They suggested two key features of ambient information visualization (i.e., aesthetic appeal and usability). Ambient information visualization not only shares similar goals to information visualization (functional or usability), but also focuses on and emphasizes the sensory outcome (i.e., beautification) and data communication rather than revealing underlying patterns. One significant trait that distinguishes ambient information visualization from other types of the visualization discipline is that its function tends to create awareness of changes in the environment that people live in without requiring any interaction in order to extract information from visual representation of data. Thus, from Skog et al.’s perspective, the visualization goal, visual experience or sensory outcome, and the usability of visualization are significant characteristics of ambient visualization.

Pousman et al. (2007) proposed “casual infovis” with three sub-domains (i.e., ambient infovis, social infovis, and artistic infovis) as a domain with various characteristics beyond the boundaries of information visualization research. Similar to Skog’s (2006) ambient information visualization concept, ambient infovis provides abstract depictions of data and reduces user interaction but emphasizes sensory outcome or aesthetic representation. Social infovis tends to be classified based on visualization content (e.g., as social networks, news, online community or collective web bookmarking) and uses techniques that visualize data structures such as node-link diagrams. Similarly to ambient visualization, artistic infovis has three main characteristics: (1) it has explicit conceptual goals for transforming data into visual representation; (2) it not only aims to represent data in aesthetic ways, but also requires some useful function or features in a system; and (3) it puts the responsibility on the viewers for visual interpretation of data. Thus, from Pousman et al.’s perspective, the goal, content, function, and outcome are significant features of casual infovis.

Taking all concepts together, I selected and classified the similar characteristics of artistic visualization into four main components: data collection and data type; artistic goal or intention; mapping design process; and outcome or visual experience. The following sections describe these four main characteristics and a holistic definition of artistic visualization.
2.2.2.1. Data Type

Data type is considered input data or information that feeds into visualization applications. According to Viegas and Wattenberg (2007), the data types of artistic visualization must be based on actual data (e.g., text, image, and numeric) rather than the metaphors, concepts or ideas, because the visual generation process requires mapping, which transforms data into representation.

2.2.2.2. Artistic Goal

The artistic goal is the artistic intention of making art that reflects, restructures, critiques, questions, and explores issues related to a particular social-cultural topic (Ramirez, 2008). It aims to abstract the complexity of data or information into sensory visual representations in which the artist’s concern is communicated. An artistic visualization project is often driven by the artist’s or designer’s own research agenda that attempts to experiment with unconventional design process and demonstrate design possibilities in order to create new visualization design solutions (Moere and Purchase, 2011). If the project is considered a part of research, the artistic visualization goal could be represented as a research goal that aims to solve some problems or provide new perspectives to viewers for perceiving data. In contrast, if the project is an art practice project, then the artistic visualization goal could be represented in the form of an artist statement that aims to reflect and express the artist’s concern.

2.2.2.3. Design Process

Design process is considered a process of visualization design composed of (1) a theoretical model underlying visualization, (2) tools or techniques used for visualization generation, and (3) data mapping strategy. Theoretical models are sometimes used as an inspiration for visual generation or used for computational analyzing process. However, there are some projects that do not appear to use any theoretical models in the mapping design process (see Table 2.3). Tools or techniques used for visual generation are considered a technical part of visualization system implementation. As suggested by Fishwick (2006), they refer to “the use of computing discipline to provide a raw medium or the subject materials for art and design.” Tools or techniques are significant components for translating the analysis and synthesis of theoretical models into computation.
The data mapping strategy is considered a process data display. According to Lau and Moere (2007), data mapping strategy can be classified into two types: data focus and mapping focus. The data focus is the message or information that users will get from visualization, which can be either intrinsic or extrinsic. Intrinsic data focus is a traditional information or data visualization technique that simplifies data complexity by employing cognitively effective visual mapping to allow users to discover patterns hidden inside the datasets. Conversely, extrinsic data focus is considered an artistic approach that aims to facilitate the communication and meaning of the dataset, and allows users to appreciate and interpret the visualization message or content.

Mapping focus is considered a process of translating data values into a visual representation, which can be either direct or interpretive. Direct mapping focus is considered a process generally driven by visual cognition and perception psychology. More precisely, it is a traditional data visualization or information visualization mapping technique that tends to use visual forms (e.g., point, line or shape) to represent specific data values in datasets. In contrast, interpretive mapping involves subjective decisions adopted from cross-disciplinary inspirations, such as interactive art, new media, graphic design, and social sciences. Interpretive mapping tends to use concepts or metaphors that are imaginative, ambiguous, unpredictable or arbitrary, based on artist or designer intentions. The mapping is interpreted as a literal form of translation without consideration of the outcome. It emphasizes the beautification and clarification of the dataset rather than revealing insight about data.

2.2.2.4. Outcome and Visual Experience

Outcome is one of the most tricky characteristics of artistic visualization because it often refers to aesthetics, qualities of sensual perception or beautification of the visualization. To avoid subjectivity, in this thesis, I use Kosara’s (2007) aesthetic criteria of sublimity to describe the outcome and visual experience of artistic visualization. According to Kosara’s (2007), the outcome of artistic visualization is either readable (pragmatic) or non-readable (artistic). From Kosara’s perspective, artistic visualization is sublime and unreadable—it transforms data into something interesting or communicates a concern rather than representing the data. Pragmatic visualization, on the other hand, is utilitarian (recognizable and readable) and considered as works situated in the information visualization domain.
However, we cannot state that the artistic visualization outcome is sublime and unreadable and pragmatic visualization is utilitarian and readable. The artistic visualization outcome can evoke a wide range of emotions (i.e., positive and negative), whether it is unreadable or readable. Some unreadable (artistic) visualization may be enigmatic and not immediately recognizable or readable for those who do not know how to read them. However, when one spends time with the visualization, understands the visual generation process and/or knows how to read the visualization, it is possible to understand and read the meaning of the visualization. Similarly, pragmatic visualization can be sublime although it is utilitarian and readable. When one takes time to explore the visualization, interacts with the system, and understands the visualization process, then the outcome of visualization can elicit a wide range of emotions, such as in We Feel Fine (Kamvar and Harris, 2011), The Dumpster (Levin et al., 2006) or The Shape of Song (Wattenburg, 2001) (see the next section). Therefore, the outcome of artistic visualization can be sublime, whether it is readable or non-readable.

Instead of identifying artistic visualization based on whether it is readable or not, this thesis uses the term “readability” to refer to how much of the information is communicated or how easy the outcome of visualization is to read, understand, communicate, and draw the meaning out of the dataset when the viewer know the visualization context. The term “legibility” is also used to refer to the amount of effort that the viewer has to spend in order to understand the outcome of visualization at first glance. Hence, the artistic visualization outcome has a wide range of readability and legibility (i.e., from low to high). Low readability refers to arbitrarily abstract representation that is hard to interpret even the viewer know the visualization context. High readability refers to the outcome of visualization that is similar to information visualization representations (e.g., chart, graph, diagram). In this case, the viewer need not spend much effort to understand the outcome of visualization at first glance. However, in some cases, abstract representation can be easily interpreted when the visualization is carefully designed\(^{14}\). High legibility refers to high amount of effort and low legibility refers to low amount of effort that the viewer has to spend in order to understand the outcome of visualization. Figure 2.20 presents and illustrates examples of artistic visualization outcome based on readability and legibility.

\(^{14}\) See The Garden of Chances by Hutzler et al., 2000.
Figure 2.20. Examples of artistic visualization outcome based on readability and legibility

*Note.* See more information about these artistic visualization projects in the next section.

Taking all characteristics together, artistic visualization can be broadly defined as "the use of computing as a medium in combination with art theory and artistic process with an intention to explore creative design space for art making, in order to provide sensory outcome (either readable or non-readable), new visual experience, and some useful functions to a viewing audience."

### 2.2.3. Examples of Artistic Visualization Projects

Table 2.7 summarizes some examples of artistic visualization projects based on the four characteristics described in the previous section.
## Table 2.7  Examples of artistic visualization projects

<table>
<thead>
<tr>
<th>Author</th>
<th>Project Name</th>
<th>Data Type</th>
<th>Goal / Intention</th>
<th>Data Set</th>
<th>Design Process</th>
<th>Tool or Technique</th>
<th>Mapping Focus</th>
<th>Data Focus</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dragulescu (2005)</td>
<td>Spam plants &amp; Spam architecture</td>
<td>Text</td>
<td>To transform useless data into aesthetic and meaningful visual representation</td>
<td>Spam email</td>
<td>N/A</td>
<td>PHP &amp; Maya: MEL - Scripting</td>
<td></td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Fry (1997)</td>
<td>Valence</td>
<td>Text or numeric</td>
<td>To propose a new way to visualize dynamic information based on different properties of an organism; To provide a qualitative feel of how the information is structured.</td>
<td>The structure of content taken from a book called “The Innocents Abroad” by Mark Twain</td>
<td>Organism theories, such as cellular automata, metabolism, homeostasis, and adaptation</td>
<td>Dynamic query^a</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Hutzler et al. (2000)</td>
<td>The Garden of Chances</td>
<td>Numeric</td>
<td>To explore the associations between abstract painting and reactive multi-agent systems</td>
<td>Meteorological data (e.g., temperature, rain, clouds or wind direction)</td>
<td>Multi-agent systems</td>
<td>Evolutionary algorithm^b</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Krcadinac et al. (2013)</td>
<td>Synesketch</td>
<td>Text</td>
<td>To enhance learning and creativity in the area of real-time text visualization by associating with other fields</td>
<td>Emotions in the text</td>
<td>Ekman's six basic emotions, Green-Amytage colour palettes</td>
<td>Bubble Chamber^c</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Harris and Kamvar (2006)</td>
<td>We Feel Fine</td>
<td>Net-work data (text)</td>
<td>To collect the world's emotions to help people understand themselves and others</td>
<td>Human feelings or emotions from blog posts in various subjects</td>
<td>Sentimental Analysis, Computational Social Psychology, Datavis</td>
<td>Various techniques borrowed from Information visualization</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Levin et al. (2006)</td>
<td>The Dumpster</td>
<td>Net-work data (text)</td>
<td>To reveal intimate perspectives, similarities, differences, and patterns in failed relationships of American teenagers</td>
<td>Online blogs post of the romantic breakups of teenagers</td>
<td>N/A</td>
<td>Java Processing</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

(Continued)
Table 2.7 (Continued)

<table>
<thead>
<tr>
<th>Author</th>
<th>Project Name</th>
<th>Data Type</th>
<th>Goal / Intention</th>
<th>Data Set</th>
<th>Design Process</th>
<th>Mapping Focus</th>
<th>Data Focus</th>
<th>Out come</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salavon (2000)</td>
<td>The Top Grossing Film of All Time</td>
<td>Image</td>
<td>To analyze, re-configure, and reveal uncanny patterns, structures, and beauty of some common products of American culture</td>
<td>Changes of moods in the film through the colours</td>
<td>N/A</td>
<td>Averaging Colour</td>
<td>N/A</td>
<td>-</td>
</tr>
<tr>
<td>(Salavon, 2002a)</td>
<td>Home For Sale 1999/2001/2002</td>
<td>Image</td>
<td>Environment of home for sale in different metro cities in a particular time</td>
<td>Changes of moods in the film through the colours</td>
<td>N/A</td>
<td>Averaging Colour</td>
<td>N/A</td>
<td>-</td>
</tr>
<tr>
<td>(Salavon, 2002b)</td>
<td>Every Playboy Centerfold, The Decades</td>
<td>Image</td>
<td>Composition &amp; photographic style that has changed in taste over the decades</td>
<td>Changes of moods in the film through the colours</td>
<td>N/A</td>
<td>Averaging Colour</td>
<td>N/A</td>
<td>-</td>
</tr>
<tr>
<td>Skog (2006)</td>
<td>Mondrian</td>
<td>Numeric</td>
<td>To make dynamic data more useful and appealing; To design effective aesthetic visualization that conveys crucial information at a glance</td>
<td>Changes of moods in the film through the colours</td>
<td>N/A</td>
<td>Averaging Colour</td>
<td>N/A</td>
<td>-</td>
</tr>
<tr>
<td>Wattenburg (2001)</td>
<td>Shape of Song</td>
<td>Numeric</td>
<td>To create a new technique used for analyzing highly structured data such as music; To reveal and compare structures or patterns in musical compositions</td>
<td>Changes of moods in the film through the colours</td>
<td>N/A</td>
<td>Averaging Colour</td>
<td>N/A</td>
<td>-</td>
</tr>
</tbody>
</table>

Note: D = Direct, IP = Interpretive, ES = Extrinsic, IS = Intrinsic, R = Readable, NR = Non-readable, NA = Not Applicable

*aDynamic query is a process that continuously updates the data that is filtered from the database (Shneiderman, 1992); bEvolutionary algorithm (EA) is the computation that uses mechanism inspired by the evolution of a plant or an animal (i.e., biological evolution); cBubble Chamber is a generative painting algorithm designed by Jared Tarbell (see, http://www.complexification.net).
Alex Dragulescu’s *Spam Plants and Spam Architecture* transformed email text (data) into plant and architecture representations (Mancuso, 2006; Whitelaw, 2008) (Fig. 2.21). The process of transforming text (data) into new representations is arbitrary and involves interpretive data mapping and intrinsic data focus. Dragulescu’s artwork demonstrated how the data art process generates meaning and information. His artwork focused on the process of data transformation to generate new representation, rather than on the final output visualization. It reflected artistic intention through visual representation.

![Spam Plants and Spam Architecture](image)

**Figure 2.21. Spam Plants and Spam Architecture**


Ben Fry’s *Valence* visualized the structure of content (i.e., text) taken from a book called *The Innocents Abroad* by Mark Twain (Fry, 1997) (Fig. 2.22). The goal was to propose a new way to visualize dynamic information and explore the relationships and structures of large datasets. The visualization design process drew inspiration from organism theories, such as cellular automata, metabolism, homeostasis, and adaptation. In *Valence*, the system dynamically presented words from the book by putting them in three-dimensional space in spherical form. Repetitive words or frequent words were moved towards the outside of the sphere, while less commonly used words were moved towards the centre, allowing the viewer to see the book’s relationships and structures.
The process of representing dynamic data involved interpretive data mapping and extrinsic data focus.

Figure 2.22. Valence: the exploration of structure and relationship inside very large datasets


Hutzler et al.'s The Garden of Chances (GOC) generated abstract visual representations of meteorological data using multi-agent systems (Hutzler et al., 2000) (Fig. 2.23). The goal was to explore the associations between abstract painting and reactive multi-agent systems. GOC produced abstract visual representations of weather data in the form of two-dimensional artificial life creatures that evolved and reacted to real world meteorological data, such as temperature, rain, clouds or wind direction. Colour contrast—coldness, warmness, darkness, and lightness—was used for temperature representation. The data representation process relied on the multi-agents theoretical model, and involved interpretive data mapping and intrinsic data focus.
Kradinac’s *Synesketch* detected and generated abstract visual representations of six basic emotions—happiness, anger, fear, surprise, sadness, and disgust—based on Paul Ekman’s emotion classification (Kradinac, 2013) (Fig. 2.24). The goal was to enhance learning and creativity in real-time text visualization in association with other fields of study, such as affective computing, synaesthesia, poetry, painting, and algorithmic art. The *Synesketch* system is composed of two visualization engines called Hooloovoo (Fig. 2.24a) and Synesmania (Fig. 2.24b) that visualized six basic emotions as simple grids of coloured squares and abstract visual patterns with different shapes and colours. The visual generation process integrated Ekman’s emotion classification theory with (1) results from Green-Armytage’s empirical research in colour and emotion perception and (2) inspiration from Piet Mondrian’s painting and Jared Tarbell’s *bubble chamber algorithm*. The data representation process used direct mapping and intrinsic data focus strategy.
Kamvar and Harris’ *We Feel Fine* collected words or sentences related to people’s emotion from blogs, microblogs, and social networking websites, and represented them as six different types of visualization (Kamvar and Harris, 2011) (Fig. 2.25). In this artwork, each visualization has unique visual styles and functions for representing human feeling or emotion. For instance, in the “madness” visualization, emotional information is displayed as a swarming mass of 1500 particles, where each particle represents a single feeling and its colour corresponds to the feeling’s tone (Fig. 2.25 [left]). In “mounds” visualization, feelings are represented by a large bulbous mound associated with statistical information, while the mound’s colour corresponds to the feeling represented (Fig. 2.25 [right]). *We Feel Fine’s* goal was to collect the world’s emotions (several million human feelings) and represent them in a way that encouraged the viewer to explore other people’s feelings in order to better understand themselves and others. The data representation process relied on various techniques borrowed from information visualization (e.g., chart or graph) and involved direct data mapping and extrinsic data focus.
Levin et al.'s *The Dumpster* collected teenagers' romantic breakup stories from online blog posts and visualized them to reveal behaviour patterns in failed relationships (Levin et al., 2006) (Fig. 2.26). *The Dumpster* had several artistic goals related to social-cultural elements, such as allowing the voyeur to observe thousands of personal stories of romantic relationships, reassuring and healing those who experience romantic breakups, and revealing how people expressed their pain through different language patterns. The Dumpster created “a group portrait” of teenagers’ romantic relationships and the visualization was represented through statistical or analytical interfaces that allowed the viewer to navigate the personal breakup stories and see differences and similarities among stories. Each story is represented by particle pile ups in two-dimensional space, while colour brightness indicated their similarity to the story selected by the viewer. The data representation process relied on various techniques borrowed from information visualization (e.g., table lens and histogram), and involved direct data mapping and extrinsic data focus.

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15 See more information in Golan Levin’s artistic statement at http://artport.whitney.org/commissions/thedumpster/statement.html

16 A term used by Lev Manovich to describes *The Dumpster*; see: http://www2.tate.org.uk/intermediaart/entry15385.shtm
Jason Salavon’s artworks often dealt with analyzing and reconfiguring American contemporary culture in order to reveal the uncanny patterns, structures, and beauty of common products of American culture, such as art, education, film or real estate (Columbus Art Museum, 2008). Salavon often used the same technique (i.e., averaging colour) to abstract data into new information and the process of representing data often involved intrinsic data focus, which is presented in three works described below.

In *Top Grossing Film of All Time* (Fig. 2.27a), Salavon visualized the colours and moods of the movie *Titanic* by abstracting the movie’s information, digitizing the entire film, and placing each frame into a left-to-right, top-to-bottom grid structure. The “averaging colour pixels” technique was used to select the best colour representation of each frame, resulting in visual representation that allowed audiences to detect changes in the movie’s colours and mood (Salavon, 2000).
In *Homes for sale* (Fig. 2.27b), Salavon visualized a single family home for sale in different metro cities around the United States. Once again, the averaging colour pixels technique was used to average the colour of the home advertisements. Each advertisement was layered on top of each other, causing the images to dissolve into abstract forms and generate a field of colour that allowed viewers to see the differences between environments and house properties (e.g., sky or house colour) at a particular time, location, and price point of homes on the market. For instance, the Dallas house image has greener grass than the Seattle house, while the Miami house image has a brighter sky than the Chicago house (Salavon, 2002a).

In *Every Playboy Centerfold (The Decades)* (Fig. 2.27c), Salavon visualized the visual composition and photographic style of a series of Playboy magazine covers from 1960 to 1990. As in *Homes for sale*, the averaging colour pixels technique was used to average the colour of each magazine cover. Each cover was layered on top of each other, causing the collection of playboy model images to dissolve into abstract forms and generate a field of colour that allowed audiences to appreciate and be aware of changes in the visual representation. The visualization unveiled the visual composition and photographic style, model body posture, skin colour, hair style or lighting that has changed in taste over the decades in the adult magazine industry (Salavon, 2002b).

![Figure 2.27. Jason Salavon’s artworks: (a.) Top Grossing Film of All Time; (b.) Homes for Sale; (c.) Every Playboy Centerfold, The Decades](http://www.salavon.com/)


Skog et al.’s *Mondrian* created an art object and information display that visualized bus departure times at the University of Gothenburg. (Skog et al., 2003) (Fig. 2.28). The goals were to design (1) a mapping strategy that was easy for viewers to read
and understand and (2) a visualization that looked aesthetically appealing. To design the visualization, the university campus’ geographic information was abstracted into several rectangles with different colours and lines. A coloured square represented each bus at the bus stop, while the square’s size indicated departure times or amount of time before the bus left. Red indicated that students needed to hurry in order to catch the bus. Yellow meant there was still time but students needed to start walking to the bus stop. Blue meant that students had plenty of time before the bus would leave. The visualization was installed and displayed on campus, showing university bus traffic information. The visualization not only functioned as an aesthetic object, but also had a practical function that allowed viewer to quickly perceive information. The data representation process was inspired by Piet Mondrian’s work and involved interpretive data mapping and intrinsic data focus.

![Mondrian: ambient bus traffic information](image)

**Figure 2.28.** Mondrian: ambient bus traffic information.


Martin Wattenberg’s *The Shape of Song* visualized and revealed complex patterns of musical form based on pitch repetition (Wattenberg, 2001) (Fig. 2.29). *The Shape of Song* was presented in an analytic interface that allowed people around the world to upload their favourite music in MIDI file format in order to see music patterns or structures. The goal of this project was a personal and artistic exploration of the nature of music aimed at creating visual representations of the overall musical form rather than the translation of notes and rhythms into color and animation (Wattenberg, 2001). The visualization reflected musical characteristics and styles, and allowed viewers to see the differences and similarities of musical patterns created by different composers. In the data representation process, Wattenberg was inspired by several information visualization techniques for visualizing string data such as DNA analysis technique. He applied these techniques and created a new method for analyzing the structure of a
piece of music and representing it in a repetition arc diagram. The data representation process involved direct data mapping and extrinsic data focus.

<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Composer</td>
<td>Title</td>
</tr>
<tr>
<td>Silt</td>
<td>Down</td>
</tr>
<tr>
<td>AC/DC</td>
<td>moe/free</td>
</tr>
<tr>
<td>Audio to Art:</td>
<td>Highway 10, 100</td>
</tr>
<tr>
<td>Alexander</td>
<td>Moments in ...</td>
</tr>
<tr>
<td>Art of Noise:</td>
<td>A Musical Coff...</td>
</tr>
<tr>
<td>Bach, J.S.</td>
<td>A Musical Coff...</td>
</tr>
<tr>
<td>Sumo</td>
<td>uuuuuu</td>
</tr>
<tr>
<td>iomega</td>
<td>uuuuuu</td>
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<td>Sash</td>
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<td>Sash</td>
<td>uuuuuu</td>
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</tbody>
</table>

Figure 2.29. The Shape of Song


The artistic examples presented in this section share similar characteristics but each project focused on different characteristics of visualization. For instance, one project heavily emphasized artistic intention and design process, while others stressed sensory outcomes and visualization function. In this section, this thesis identified the research area within the artistic visualization domain. I reviewed and analyzed artistic visualization’s characteristics, which will be used to frame this thesis’ work and design process. Figure 2.30 summarizes this section’s literature review of artistic visualization.
2.3. Summary

To summarize, this chapter reviewed human movement study in art and determined that early human movement study used drawing as a medium to record animal locomotion and human motion patterns as well as the causes and effects of human anatomy and human motion (e.g., muscle movements or body posture). The invention of chronophotography changed the way artists worked as they attempted to record, capture, abstract, express, convey, and represent fundamental human movement properties (e.g., body, space, and time) in abstract visual forms.

In parallel with artistic practice, many movement theories have been invented and Laban Movement Analysis (LMA) is the most well-known and widely used framework used for describing the qualitative aspect of movement. This development allows movement observers to analyze human motion and obtain more high-level information, such as different movement qualities. In a digital technology context, LMA has been—and continues to be—widely used in art and computing. While LMA has broad application across research fields, this section reviewed some human movement and visualization examples and demonstrated that integration of LMA into the visualization domain is still under exploration, specifically visualizing movement qualities.

However, the visualization research area is large and there are many subdomains. To find an appropriate area for movement quality visualization, the literature of visualization section reviewed (1) the state of the art of visualization research, (2) various concepts used to describe artistic visualization, and (3) the visualization domain wherein artists and scientists employ computing as a medium to explore creative design space for art making and provide new visual experience to a viewing audience. These
concepts were analyzed in order to identify the key characteristics framing the artistic visualization domain and the direction of this research. To demonstrate artistic visualization characteristics in visualization work, I also presented examples of artistic visualization projects.

Finally, pulling two domains together, this chapter identified research gaps in articulating how to utilize LMA Effort as a design resource for visualizing movement quality or as an underlying model to capture, represent, and map high-level semantic movement information (i.e., movement quality) to a visualization system. This will contribute new knowledge to the field of human movement and artistic visualization.
Chapter 3.

Research Methodology

This chapter describes the research methods and approaches used in this thesis (Fig. 3.1). First, practice-based research is used as the main strategy to develop a series of movement quality visualization systems by exploring the design process grounded on my artistic practice. The goals are (1) to explore the question, “How can the Laban Movement Analysis (LMA) framework be applied in a design process and used as an underlying model to capture, map, and represent movement quality to a visualization system?” and (2) to devise a set of design criteria for visualizing movement quality.

Secondly, in a broad context, the exploratory research approach is used within practice-based research to frame the direction of design process, with a focus on experimenting with different design criteria to reveal novel design solutions. To apply the exploratory research approach within a visualization context, visualization exploration\(^1\) – an exploratory design approach – is used to describe research and design activity that are not usually adopted by the main streams of the visualization research community.

Third, usability testing is used to measure the effectiveness or communicative ability of visualization systems. Evaluating communication through visualization (CTV), one type of visualization evaluation, is used in this thesis as a guideline for describing and clarifying evaluation goals, questions, and methods used in the visualization system evaluation (see section 3.3). Online survey is used as a technique to obtain participants’ experience and feedback on three visualization systems. The comparative method is used as a part of practice-based research to critique, analyze, and compare the strengths and weaknesses of three visualization systems’ design. Usability testing

\(^1\) Visualization exploration is one of three domains or types of design approaches in information visualization research described in a model of design in visualization research, see section 3.2.2.
results are used to support the comparative analysis process. Taken together, these research methods and approaches comprise this thesis’ research methodology (Fig. 3.1).

**Figure 3.1.** The overview of research approaches and methods used in this thesis.

### 3.1. Practice-Based Research

Practice-based research is a research activity that investigates and contributes to creating new knowledge grounded on practice and outcomes of that practice. This type of research is usually referred to as reflection practice, reflective practice or reflection-in-action. Donald Schön, a philosopher and educator, defines these terms as “the process of thinking which accompany doing, and which constantly interact with and modify ongoing practice in such a way that learning takes place” (Schön, 1983). This notion is also known as reflective practice (i.e., knowing-in-action), which attempts to bridge traditional research and practice. Reflective practice involves thinking and analyzing one’s action with the aim of improving one’s professional practice (Imel, 1992). It engages in "a continuous cycle of self-observation and self-evaluation in order to understand [one’s] own actions with the aim to observe and refine practice in general on going basis” (Brookfield, 1995; Thiel 1999 cited in Cunningham, 2001).

In an art and design context, reflection practice or reflective practice is contextualized as practice-based arts research, where the designing, developing, and art making of artefact (e.g., images, music, designs, models, digital media, performance,
and exhibition) is the central activity in the research process (Candy, 2006; Candy and Edmonds, 2010). This process focuses on thinking and reshaping action while practicing and the outcome is to know how rather than to know what (Gray and Malins, 2004; Schön, 1983). In this process, the artefact is the evidence of practice because it contributes to creating new knowledge gained from art practice or art-making process. This new knowledge embedded in artefacts is sometimes known as material culture\(^2\) (Candy and Edmonds, 2010). This type of research is characterized as involving iterative, dynamic, reflective, and revelatory processes (Gray and Malins, 2004; Sullivan, 2009).

Reflective practice is sometimes referred to as “research through art and design,” where art and design is the vehicle of the research (e.g., materials research, development work or action research), and a practitioner seeks to understand the design process and develops new design methods through artistic practice (Frayling, 1993). Candy (2006) stated that this type of practice refers to “practice-led research” which aims to advance knowledge about practice or within practice rather than gain new knowledge partly by means of practice and the outcomes of that practice. Additionally, reflective practice overlaps with the notion of “research for art and design,” which describes research where the outcome is an artefact and thinking is embodied in the artefact. This type of work is not intended to communicate knowledge in the sense of verbal communication, but in the sense of knowledge embedded in the artwork (Frayling, 1993). Thus, critical thinking and research process documentation is not the main focus for this type of work. In higher education, the artefact alone is not considered academic research. Thus, the outcome of practice-based research (i.e., artefact) in academic context must be accompanied by the documentation of the research process, as well as textual analysis and critical reflections (Candy, 2006).

In computer human interaction (HCI), interaction design research, and interactive arts or new media art practice, practice-based research is composed of three main elements: practice, theory, and evaluation. Each element has different activities and outcomes within its own trajectory (Edmonds and Candy, 2010). Figure 3.2 presents the

\(^2\) Material culture is a term used to describe the objects produced by human beings, including buildings, structures, monuments, tools, weapons, utensils, furniture, art, and indeed any physical item created by society, see: http://www.oxfordreference.com/view/10.1093/oi/authority.20110810105347145

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three elements and five stages of activities and outcomes of practice-based research applied in this thesis.

**Figure 3.2.** The three elements and five stages of practice-based research applied in this thesis

*Note.* Adopted from practice and theory reflexivity model (see Edmonds and Candy 2010).

In practice trajectories, the main research activities are creating, exhibiting, and reflecting, while outcomes are works such as systems, physical artefacts, exhibitions or installations—and in the case of this thesis, three visualization systems. In theory trajectories, the main activities are reading, thinking, writing, and developing, and outcomes are frameworks such as questions, criteria or issues. In evaluation trajectories, the main activities are observing, recording, analyzing, and reflecting, while outcomes are findings leading to new or modified works and frameworks (Edmonds and Candy, 2010). These three elements of practice-based research (practice, theory, and evaluation) are not separated components because the research processes or activities tend to move back and forth between the three trajectories. Thus, the research activities do not necessarily occur in chronological order or in a sequence. In a digital technology context, practice-based research has been used by various artists, designers, and researchers as a strategy for graduate research projects (e.g., Baker, 2010; Bogart,
2008; Costello, 2009; Fry, 2004; Gwilt, 2009; Johnston, 2009; Reas, 2001; Schiphorst, 2008; Seo, 2011).

I undertook this thesis in collaboration with movement experts and computer scientists, in order to develop visualization systems for representing movement quality. The primary goals are (1) to explore how the Laban Movement Analysis (LMA) framework can be applied in a design process and used as an underlying model to capture, map, and represent the movement quality of a visualization system, (2) to communicate movement quality information in expressive ways, (3) to construct a framework that describes a design process for articulating movement quality visualization, and (4) to devise a set of design criteria for visualizing movement quality. Table 3.1 summarizes the practice-based research stages, activities, and outcomes associated with each chapter of this thesis.

Table 3.1. Summary of practice-based research stages, activities, and outcomes associated with each chapter of this thesis

<table>
<thead>
<tr>
<th>Research Stage</th>
<th>Activity</th>
<th>Outcome</th>
<th>Thesis Chapter</th>
</tr>
</thead>
<tbody>
<tr>
<td>1, 2</td>
<td>• Review literature</td>
<td>• Missing element in the existing research literature</td>
<td>2. Literature Review</td>
</tr>
<tr>
<td></td>
<td>• Define research area (i.e., artistic visualization and human movement)</td>
<td>• Research goals and contributions clarification</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Formulate research questions</td>
<td>• Research methods and techniques used in practice-based art research</td>
<td>3. Research Methodology</td>
</tr>
<tr>
<td></td>
<td>• Search for research methods and techniques</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Develop an artistic framework and design criteria for visualizing</td>
<td>• Three mapping design strategies</td>
<td>4. Designing EMVIZ Visualization</td>
</tr>
<tr>
<td></td>
<td>movement quality</td>
<td>• Three visualization systems</td>
<td>System</td>
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<td></td>
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<td>• Interactive installation</td>
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<td></td>
<td></td>
<td>• Visual dashboard application</td>
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<td></td>
<td></td>
<td>• Interactive dance performance</td>
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</tr>
<tr>
<td>3, 4, 5</td>
<td>• Evaluate three visualization systems</td>
<td>• Usability testing design structure and study plan</td>
<td>5. Evaluation and Data Analysis</td>
</tr>
<tr>
<td></td>
<td>• Analyze usability testing data</td>
<td>• Statistical results</td>
<td>6. Usability Testing Results</td>
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<tr>
<td></td>
<td>• Critique, analyze, and compare three visualization systems' design</td>
<td>• Comparative results of three visualization systems</td>
<td>7. Comparative Analysis</td>
</tr>
<tr>
<td></td>
<td>criteria</td>
<td></td>
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<tr>
<td>5</td>
<td>• Modified framework or design criteria for representing movement quality</td>
<td>• Artistic framework for visualizing movement quality</td>
<td>8. Discussion and Conclusion</td>
</tr>
<tr>
<td></td>
<td>• Examples of design criteria usage</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Summarize and discuss study limitations</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3.2. Exploratory Design

This section describes the notion of exploratory design that artists and designers from various disciplines use as a strategy to explore creative possibilities beyond traditional practice. Exploratory design or experimental art has its root in the history of the avant-garde³ in the early 19th century. In this art movement, avant-garde refers to highly innovative and path-breaking artists who do not follow traditional approaches but manifest themselves in non-traditional approaches to artistic and cultural production (Nersessian, 2004).

For instance, Marcel Duchamp used the urinal (ready-made object) in an art context so that its useful significance disappeared under the new title and point of view, creating a new thought for the object; this represents art primarily as a mental act rather than a visual one (Aoki, 2004; Howarth, 2000). Similarly, exploratory design often refers to an exploratory process or artistic activity that seeks to discover new artistic or design possibilities outside mainstream traditional practice. This process aims to push the boundaries of traditional practice and conventional ways of thinking in various art and design domains, such as painting, communication design, film, architecture, theatre, and fashion. In each domain, the exploratory design approach is concerned with different experimental criteria (e.g., theory, technique, medium) because of the domains’ different characteristics.

For instance, in experimental architecture, architects are concerned with architectural concept development and exploration that search for design possibilities or solutions outside traditional architectural research paradigms in which form, material, technology, constructional methodology, and social structure are the main focus (Cook, 1970; Myers et al., 2004). This architectural experimental activity does not aim to resolve any problems or answer questions nor require concrete construction plans, but to explore architectural study freely without involving clients (Wong and Kim, 2011). In experimental film and cinema, filmmakers are concerned with conceptual thinking that explores and experiments with narrative, image, material, audience, and technology

³ Avant-Garde refers to innovative or experimental concepts or works, or the group of people who are dedicated to the idea of art as experiment and revolt against tradition (The Oxford Dictionary of Literary, 2008), see more information in Bürger (1984). Theory of the Avant-garde. Manchester University Press.
beyond the scope of commercial film and cinema (Boruszkowski, 1985). In experimental theatre, theatre artists or designers explore and experiment with theatre elements outside traditional practice, such as the relationships between audience and performers, audience participation, the performer’s body language, playwriting, verbal usage, lighting effect, and stage props (Roose-Evans, 1996). Figure 3.3 presents some examples of experimental work in architecture, film and cinema, fashion, and theatre.

Figure 3.3. Examples of experimental work in architecture, film and cinema, fashion, and theatre

3.2.1. Design Exploration: A Model of Interaction Design Research

In a modern design context, the experimental approach has also been—and continues to be—used in interaction design. Daniel Fallman used the term “design exploration”—one of the design research activities described in the model of interaction design research—to describe the experimental approach in an interaction design context and emphasize how it is different from other design research approaches (Fallman, 2008). The interaction design research model (Fig. 3.4) describes, categorizes, and differentiates three research approaches used in the field of interaction design: design practice, design studies, and design exploration (Fallman, 2008).

![Figure 3.4. A model of interaction design research](image)


Design practice is a research approach that involves practicing interaction design outside of academia (e.g., in commercial interaction design organizations) (Fallman, 2008). This means the designer is a researcher working in a multidisciplinary team to develop products under some research problems and working conditions, such as an
Intern designer in a design company. More precisely, design practice requires a customer or client and can be understood as traditional design practice or commercial art. In design practice, a designer learns to communicate with other teams (e.g., engineers, managers, sales representative, customers) and solves design and marketing problems. Design practice does not aim to limit designer creativity, but it requires cooperation with other teams under some constraints. In this circumstance, a designer learns to scope a research question (e.g., what kinds of design technique and how such techniques are used to solve the problems), uses their own experience to achieve the design goal, and collaborates with the team to create a successful result (Fallman, 2008).

In contrast, design studies is a research activity that seeks to understand, contribute, and accumulate the body of knowledge related to design theory, methodology, history, and philosophy. Design studies can be described as research activity that seeks to understand, explain, describe or analyze design. Thus, the design studies approach focuses on the theoretical and philosophical aspects of art and design rather than practice and it is usually situated in academia.

Design exploration is similar to design practice but its research activity focuses on exploring, searching for, and analyzing possibilities outside of current research paradigms through critical analysis and experimentation to reveal alternative design solutions. Design exploration can be compared to the ideals of contemporary art or *avant-garde* and usually focuses on issues of aesthetics and experiences. Fallman (2008) described design exploration as research activities that seek to experiment, critique, provoke or subvert the research societies. Artists or designers who employ design exploration as a research approach often seek to test ideas and to ask what would happen if they employed such theories or techniques in their art or design practice. The productions, artefacts or the outcomes of design exploration are sometimes known as material culture, which benefits not only design academia and industry but also many fields in society at large. In general, this thesis employs design exploration as an approach to plan research direction and to define the contributions of this practice-based Ph.D. thesis. The following section describes and presents the design exploration approach used in a visualization research context.
3.2.2. **Visualization Exploration: A Model of Three Roles of Design in Information Visualization Research**

In visualization research, Moere and Purchase applied a model of interaction design to the visualization domain by comparing the design research activities of interaction design with visualization research to establish three roles of design in information visualization research: visualization practice, visualization studies, and visualization exploration (Moere and Purchase, 2011). These three roles share similar characteristics to a model of interaction design research, such as visualization practice in commercial design, visualization studies in academic research, and visualization exploration in experimental art and design. Figure 3.5 presents a model of the three design roles in information visualization research defined by Moere and Purchase.

![Figure 3.5. A model of three roles of design in information visualization research](image)


Similarly to design practice, visualization practice refers to visualization activities or projects that are accomplished outside of academia (i.e., commercial enterprises). Visualization practice activities are often driven by designers in collaboration with other teams in commercial companies to develop and provide design solutions to customers.
However, the goal of visualization practice is not only to profit from visualization design services (e.g., information graphic design or data analytics) but also to seek possibilities to bring together theoretical knowledge and practice in visualization research.

In contrast to visualization practice, visualization studies tends to involve traditional academic research that seeks to understand, contribute, and accumulate visualization knowledge through empirical experimentation. Visualization study has its root in computer science and researchers often focus on understanding existing technical problems and proposing new design techniques to solve them. Careful evaluation is performed to ensure that such techniques are successful. Thus, visualization studies focus on the utility of the visualization, which sometimes overlook aesthetics.

Visualization exploration research activities, unlike visualization practice and visualization studies, are often driven by the artist's or designer's own research agenda that attempts to experiment with unconventional design process and demonstrate design possibilities in order to create new visualization design solutions (Moere and Purchase, 2011). The goal of visualization exploration is idealistic and not focused on resolving issues or addressing the requirements of “utility,” but rather on questioning, restructuring, critiquing, and presenting possible design solutions through experimentation. The outcomes of visualization exploration are not generic but specific in form and artistic intent. Their concepts do not have to be easy to decipher, as long as they reflect the artistic intention or research objective. In my research, I chose visualization exploration as a design strategy because it allows me to experiment with different types of design strategies and computation techniques that are not usually applied within traditional visualization research. Visualization exploration strategy is well-suited to the design process of artistic visualization (see previous chapter section 2.2.2), which is the main area of this thesis.

3.3. Usability Testing and Evaluating Communication through Visualization (CTV)

Usability testing has a close relationship to traditional research methods in the humanities and science, such as observation in ethnographic research and experimental
design or controlled experiments in scientific research (Lazar et al., 2010). For instance, observation in ethnographic research aims to understand the context of people, groups, and organizations, while usability testing aims to understand the flaws in a product, service or early prototype of computer interfaces. The measurement criteria for usability testing are task performance and time performance, similar to experimental design or controlled experiments in scientific research.

From a broad perspective, usability testing refers to the evaluation of a product, service or early prototype of computer interfaces (i.e., the test subject), in which representative users are asked to complete several tasks in a representative environment (Lewis 2006 cited from (Lazar et al., 2010; Usability.gov, 2013)). In general, the main goals of usability testing are (1) to improve the quality of the test subject in order to find flaws that cause problems for users and (2) to test to what extent the test subject achieves specific goals with effectiveness, efficiency, and satisfaction in a specified context of use (Bevan, 2009; Lazar et al., 2010).

In the information visualization research community, there are many types of usability tests to choose from, depending on the researcher’s evaluation goal (e.g., user performance, user experience, collaborative data analysis), while the scope of evaluation varies in the different stages of visualization development, such as pre-design, design process, prototype, deployment, and re-design (Lam et al., 2011). To correctly select evaluation types, questions or methods for this thesis, I referenced Lam et al.’s (2011) extensive literature review of over 800 visualization publications from major information visualization conferences around the world (e.g., Eurovis, InfoVis, IVS, and VAST) in order to describe what might be the most effective evaluation for thesis outcomes.

Lam et al.’s (2011) paper reviewed the current state of evaluation practices in the information visualization research community, analyzed different evaluation scenarios, and summarized the most common evaluation types found in the field. The authors reported that there are seven most commonly encountered evaluation scenarios in information visualization research (Table 3.2).
### Table 3.2  Seven evaluation scenarios in information visualization research community.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Description</th>
<th>Questions</th>
<th>Example Methods</th>
</tr>
</thead>
</table>
| EWP: Evaluating Environments and Work Practices | Derive design advice through an understanding of the work, analysis, or information processing practices by a given group of people with or without software use | What is the context of use of visualizations? In which daily activities should the visualization tool be integrated? What are the characteristics of the identified user group and work environments? What data is currently used and what tasks are performed on it? What kinds of visualizations are currently in use? How do they help to solve current tasks? What challenges and usage barriers can we see for a visualization tool? | Field Observation  
Interviews  
Laboratory Observations                                      |
| VDA: Evaluating Visual Data Analysis and Reasoning | Assess a how an information visualization tool supports supports analysis and reasoning about data and helps to derive relevant knowledge in a given domain | How does a visualization or tool support... data exploration?; processes aimed at seeking information, searching, filtering, and reading and extracting information?; knowledge discovery?; the schematization of information or the (re-)analysis of theories?; hypothesis generation?; interactive hypothesis examination?; decision making?; communication and application of analysis results? | Case Studies  
Controlled Experiments.                                      |
| CTV: Evaluating Communication through Visualization | Assess the communicative value of a visualization or visual representation in regards to goals such as teaching/learning, idea presentation, or casual use | Do people learn better and/or faster using the visualization tool? Is the tool helpful in explaining and communicating concepts to third parties? How do people interact with visualizations installed in public areas? Are they used and/or useful? Can useful information be extracted from a casual information visualization? | Controlled Experiments  
Field Observation and Interviews.                               |
| CDA: Evaluating Collaborative Data Analysis | Understand how (well) an information visualization tool supports collaborative team work and data analysis by groups of people | Does the tool support effective and efficient collaborative data analysis? Does the tool satisfactorily support or stimulate group analysis or sensemaking? Does the tool support group insight? Is social exchange around and communication about the data facilitated? How is a collaborative visualization system used? How are certain system features used during collaborative work? What are patterns of system use? What is the process of collaborative analysis? What are users' requirements? | Heuristic Evaluation  
Log Analysis  
Field or Laboratory Observation.                                  |
| UP: Evaluating User Performance | Objectively measure how specific features affect the performance of people with a system | What are the limits of human visual perception and cognition for specific kinds of visual encoding or interaction techniques? How does one visualization or interaction technique compare to another as measured by human performance? | Controlled Experiments  
Field Logs.                                                        |
| UE: Evaluating User Experience | Elicit subjective feedback and opinions on a visualization tool | What features are seen as useful? What features are missing? How can features be reworked to improve the supported work processes? Are there limitations of the current system which would hinder its adoption? Is the tool understandable and can it be learned? | Informal Evaluation  
Usability Test  
Laboratory Questionnaire.                                       |
| AEV: Automated Evaluation of Visualizations | Automatically capture and measure characteristics of a visualization tool or algorithm | Is this layout algorithm faster than state of the art techniques? Under what circumstances? How does the algorithm perform under different volumes of data and number of dimensions? What is the best arrangement of visual features in the visualization to optimize the detection of interesting patterns? What is the extent to which the current visualization deviates from a truthful representation of underlying data? What is the best ordering of visual items to speed up visual search? | Algorithmic Performance Measurement  
Quality Metrics.                                                  |

Note. See Lam et.al (2011, p. 18)
In this thesis, I chose the Evaluating Communication through Visualization (CTV) scenario as a guideline to evaluate the outcomes of this practice-based research (i.e., three visualization systems). CTV is the assessment of the communicative value of a visualization or visual representation in regards to goals such as teaching, learning, idea presentation or casual use (Lam et al., 2011). CTV’s focus is studying how communication can be supported by visualization; the main goal is to measure how effectively such messages or information are delivered and acquired by individuals or groups. As in this thesis, the goal is to evaluate the communicative ability of visual representations of movement quality generated by different versions of a visualization system. The evaluation addresses to what extent movement quality information can be recognized or extracted from abstract expressive visualizations. Lam et al. (2011) state that CTV evaluation usually addresses the following research questions:

- Do people learn better and/or faster using the visualization tool?
- Is the tool helpful in explaining and communicating concepts to third parties?
- How do people interact with visualizations installed in public areas? Are they used and/or useful?
- Can useful information be extracted from a casual information visualization?

This thesis uses these questions as a guideline to frame the evaluation of visual representations generated by three visualization systems (see Chapter 5). To answer the questions, (1) controlled experiment and (2) field observation and interviews are the two most used methods for measuring communicative ability of the visualizations. Controlled experiment is a quantitative approach adopted from psychology research that involves hypothesis testing, and it is widely used in HCI research to evaluate system interfaces and user interaction, and to understand how people interact with them (McGuffin and Balakrishnan, 2005; Moyles and Cockburn 2005 cited from Blabdford et al., 2008). In information visualization research, controlled experiment is a common research approach that has been—and continues to be—used for evaluating visualization systems. Field observation and interviews, on the other hand, are qualitative approaches used in ethnographic research, and it is commonly used in HCI and the information visualization domain to evaluate and obtain participants’ feedback on system interfaces, user interaction, user cognitive process, and so on. The next section presents examples of the application of the CTV scenario and the two evaluative approaches described above.
3.3.1. Examples of CVT Evaluation Approach

Ambient visualization\(^4\) or informative art\(^5\) is a good example of the CTV evaluation scenario. For instance, Skog et al. presented ambient bus traffic visualization (Fig. 3.6), inspired by a Piet Mondrian painting, in abstract visual compositions (Skog et al., 2003).

![Figure 3.6. Ambient bus traffic information](image)


In this example, the university campus geographic information was abstracted into several rectangles with different colours and lines. A coloured square represented each bus at the bus stop while the colour of the square indicated departure times or amount of time before the bus left. Red indicated that students needed to hurry in order to catch the bus. Yellow meant there was still time but students needed to start to walking to the bus stop. Blue meant that students had plenty of time before the bus would leave. The visualization was installed and displayed on the campus showing university bus traffic information. To evaluate how effectively the bus traffic information was delivered and acquired by students, several students were recruited to evaluate this ambient visualization. Qualitative research method and observational and interview techniques were used to obtain participant feedback on the system. This example

---

\(^4\) Ambient visualization is defined as a category of data representations that conveys time-variant information in the periphery of human attention, see: Moere, A.V. (2007). *Towards Designing Persuasive Ambient Visualization* (pp.48-52). Presented at The Design and Evaluation of Ambient Information Systems Workshop, Toronto, Canada.

\(^5\) Informative art refers to a combination of the idea of using artworks to convey information or pieces of art that dynamically reflect and therefore in some ways represent information, see: Redström, J., Skog, T., & Hallnäs, L. (2000). Informative Art: Using Amplified Artworks As Information Displays. In *Proceedings of DARE 2000 on Designing Augmented Reality Environments* (pp. 103–114). New York, NY, USA: ACM.
demonstrates the use of a qualitative approach (i.e., observation and interview) to evaluate ambient visualization.

Another example of ambient visualization is a textual emotion recognition and visualization system called Synesketch, which detects and generates abstract visual representations of six emotional types (Fig. 3.7) based on Paul Ekman’s emotion classification (Krcadinac et al., 2013).

![Image of emotion visualization]

**Figure 3.7. Six examples of emotion visualization: anger, happiness, surprise, disgust, sadness, and fear**


*Synesketch* detects six basic emotions in the text and represents them in an abstract expressive animation based upon the emotion type and intensity of interpreted textual emotions. The visual properties (e.g., colour, size, and shape) change according to the type and intensity of recognized emotion. Participants were recruited to evaluate their ability to recognize and differentiate the emotion types communicated by *Synesketch*. The quantitative research method and online survey technique were used to obtain participant feedback on the system. In the evaluation process, participants were asked to watch six basic emotion visualization videos generated by *Synesketch* and associate each of the six emotional types with the video that best matched the given emotional type. Descriptive statistics and several inferential statistics methods were
used to analyze the survey data. This example exemplifies the use of the quantitative approach of controlled experiment and online survey technique to measure the communicative ability of abstract expressive visualizations.

A third example is a computer-generated artwork called *The Garden of Chances* (GoC) (Fig. 3.8), which generated abstract visual representations of meteorological conditions using multi-agent systems (Hutzler et al., 2000; Renault and Hutzler, 2000).

![The Garden of Chances](image)

**Figure 3.8.** The visualization of meteorological conditions at different times of the year (winter, spring, summer, and fall)


GoC explored the associations between abstract painting and reactive multi-agent systems. The system simulated the evolution of a plant or animal that reacted to real-world meteorological data (e.g., temperature, rain, clouds or wind direction). GoC mapped the meteorological data to a set of two-dimensional shapes and colour contrast to generate abstract visual representations that created awareness of climate changes. Participants were recruited to evaluate to what extent information could be perceived from the visualization and how quickly participants were able to perceive information in comparison to classic representations, such as text and pictograms.

The controlled experiment quantitative research method was used to obtain participant feedback on the system. In the evaluation process, participants were shown a computer screen separated into two main windows. The left window displayed the visualization while the right window showed an interface with five sliders representing five variables: temperature, cloud cover, rain, wind speed, and wind direction. To familiarize themselves with the interface, participants were asked to use it for three
minutes by adjusting the sliders to see the corresponding visual representation on the left window. In the first evaluation task, the computer randomly generated values for five variables resulting in the visualization on the left window. Participants were asked to adjust the five variables (i.e., five sliders) to match the computer-generated visualization. This tested how much information participants perceived and extracted from the abstract visualization. In the second evaluation task, participants were asked to repeat the task, but the left window presented text and pictograms of weather conditions instead of a GoC-generated visualization. This task tested the performance of GoC representation in comparison to classic representations (i.e., text and pictograms) by measuring how quickly participants were able to perceive information from three different representations. This example demonstrates the use of the controlled experiment quantitative approach to measure the communicative ability of abstract visualizations in comparison to classic representations.

To summarize, the Evaluating Communication through Visualization (CTV) scenario is used in the visualization research community to frame evaluation direction by describing how it differs from other evaluation scenarios. CTV presents the quantitative and qualitative research approaches used for evaluating visualization communication. In this thesis, I adopted the quantitative controlled experiment approach using online survey as a technique, with closed-ended and open-ended questions to measure the communicative ability of the visualizations systems\(^6\) (i.e., the outcome of practice). The results from this evaluation phase are used to support the analytical results of the comparative analysis method (see next section). To understand how participants react to the visualization or to have a better understanding of which mapping variables (e.g., shape, colour or size) or computation techniques are the best among three visualization systems, an interview technique or a comparative deep reading study can be conducted in future work.

\(^6\) See the limitations of this study in Chapter 8, section 8.41.
3.4. Comparative Analysis

Comparative method refers to the systematic study and analysis of a small number of cases that focus on similarities and contrasts among cases (Collier, 1993). It provides a high level of discussion that evaluates relevant similarities and differences between two or more cases by revealing the strength and weakness of each case. The comparative method has been employed in various research areas of social sciences (e.g., political science, education, history, and cross-cultural studies) and the art and design domain (Gray and Malins, 1993). In art and design, comparative analysis is usually used to compare the characteristics of artwork, design or existing creative works to reveal unexplored areas or to compare older work with newer work proposed by an author in order to demonstrate that the new work is a novel research solution.

For this thesis, the comparative method is used to compare design features or criteria (i.e., metaphoric mappings, design rules, computations, and design theories) used in three different versions of a visualization system (see Chapter 4). Usability testing results are used to support the comparative analysis process. The comparative analysis results demonstrated critical understanding about my art practice—developed through the analysis process—and revealed the strength and weakness of each design strategy, which led to the final design criteria for visualizing movement quality. Figure 3.9 presents an overview of the comparative analysis process.

Figure 3.9. The overview of comparative analysis process
3.5. Conclusion

In this chapter, I have presented the research approaches and research methods used in this thesis, described as follows:

- **Practice-based research** was undertaken to explore, investigate, and contribute to creating three versions of a movement quality visualization system grounded on my artistic practice.

- In the design process, an exploratory approach was used as a strategy to explore creative possibilities beyond traditional practice. More precisely, visualization exploration was used as an approach to (1) explore metaphoric mappings, (2) experiment with different computations, and (3) integrate design theories to create three different design criteria for representing movement quality. The outcomes of this process are three visualization systems and a framework for visualizing movement quality.

- **Usability testing** was used as a method to obtain participant feedback and evaluate three visualization systems. CTV scenario was used as a guideline to frame the elements of user study design such as usability testing questions and design experiment methods. Three evaluation examples of artistic visualization systems were introduced to describe the quantitative approach (i.e., controlled experiment) and qualitative approach (i.e., observation and interviews) used in usability testing. In this thesis, controlled experiment was used as a method for visualization evaluation and online survey was used as a technique to obtain participant feedback on three visualization systems.

- To provide a high level of discussion and analysis and identify the pros and cons of the three visualization systems, the comparative method was used to analyze, critique, and compare the three visualization systems’ design features, while the results from user study sessions were used to support the comparative analysis.

Taken together, these research methods and approaches comprise the research design of this thesis. In the next chapter, I describe three visualization systems’ implementation and system usage derived from practice-based research and the exploratory design process.
Chapter 4.

Designing the EMVIZ Visualization System

This chapter describes the design process and visualization system implementation developed as a part of this practice-based research. In Chapter 2, the historical background to two primary categories that assist in framing my research in the area of human movement visualization and related works were summarized and described. In Chapter 3, research approaches and methods (i.e., practice-based research, exploratory design, usability testing, and comparative analysis) used in different aspects of my research were described. In this chapter, I describe the movement model that underlies the visualization system, artistic process, and system design for creating a series of interactive artistic visualization systems – called EMVIZ: L, Sketch, and Motion-Agent – that generate dynamic visual representations of human movement quality.

4.1. Laban Movement Analysis (LMA) Effort Theory

To design the visualization system for capturing and representing movement quality information, LMA Effort theory was used as an underpinning model. In the LMA system, movement quality is defined through its Effort. Effort analysis categorizes human movement quality using four factors: Space, Time, Weight, and Flow. Each of these Effort factors is a continuum bounded by two extreme values. The value at one end of the continuum is the result of “indulging” through the Effort, while the value at the other end is the result of “fighting” or “condensing” through the Effort (Laban and Lawrence, 1974). Space is related to personal attention to the surrounding environment and direct or indirect interaction with it. A multi-focused intent results in Indirect attention to movement, while purposeful and singularly focused intent results in Direct movement.
Time is related to personal decision or the mover’s sense of urgency. A sense of lingering is represented as Sustained Time, while a sense of urgency is represented as Sudden Time. Weight is related to personal intention or the mover’s sense of the impact of one’s movement. A buoyant attitude creates Light Weight, while a vigorous presence creates Strong Weight. Flow is related to personal progression or the feeling of “aliveness” that is marked by the ability to move between mental states with fluency. A sense of abandon marks Free Flow and a feeling of restraint or precision marks Bound Flow. Combining two and three Effort factors creates six States and four different Drive movements (see Table 4.1).

**Table 4.1. Six States (awake, remote, stable, dream, rhythm, and mobile) and four Drives (action, passion, spell, and vision).**

<table>
<thead>
<tr>
<th>States and Drives</th>
<th>Characteristics</th>
<th>Effort Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Awake:</td>
<td>Thinking and intuiting (Where and When)</td>
<td>Space &amp; Time</td>
</tr>
<tr>
<td>Remote:</td>
<td>Thinking and feeling (Where and How)</td>
<td>Space &amp; Flow</td>
</tr>
<tr>
<td>Stable:</td>
<td>Thinking and sensing (Where and What)</td>
<td>Space &amp; Weight</td>
</tr>
<tr>
<td>Dream:</td>
<td>Sensing and feeling (What and How)</td>
<td>Weight &amp; Flow</td>
</tr>
<tr>
<td>Rhythm:</td>
<td>Sensing and intuiting (What and When)</td>
<td>Weight &amp; Time</td>
</tr>
<tr>
<td>Mobile:</td>
<td>Intuiting and feeling (When and How)</td>
<td>Time &amp; Flow</td>
</tr>
<tr>
<td>Action:</td>
<td>Action oriented movement</td>
<td>Space, Time, and Weight</td>
</tr>
<tr>
<td>Passion:</td>
<td>Emotional or passionate movement</td>
<td>Time, Weight, and Flow</td>
</tr>
<tr>
<td>Spell:</td>
<td>Engaging, persuasive or seductive movement</td>
<td>Space, Weight, and Flow</td>
</tr>
<tr>
<td>Vision:</td>
<td>Movement without a sense of self</td>
<td>Space, Time, and Flow</td>
</tr>
</tbody>
</table>


In everyday movement, some parameters are emphasized, while others are minimized (Laban and Lawrence 1974). For instance, when a mover is in what Laban calls the Action Drive, their attention to Flow is minimized. In the Action Drive, the extreme values of Space, Time, and Weight combine to create eight qualities (Table 4.2). These movement qualities are so prevalent in daily activity that Laban calls them the Basic-Effort-Actions (Laban and Lawrence, 1974). However, these Basic-Effort-Actions are not gestures alone. When someone’s hand is waving to say hello, for instance, we could describe the movement as having a gliding or dabbing quality. Therefore, Basic-Effort-Actions can be used to describe movement or treated as qualitative descriptors of gestural movement. Figure 4.1 shows screen captures of a
Certified Laban Movement Analyst performing the eight movement qualities described in Table 4.2.

**Table 4.2. Effort parameters, their extreme values, and quality descriptions and examples for each of the eight Basic-Effort-Actions**

<table>
<thead>
<tr>
<th>Effort Factor</th>
<th>Basic-Effort-Actions</th>
<th>Movement Quality Description and Example</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Space</strong></td>
<td><strong>Time</strong></td>
<td><strong>Weight</strong></td>
</tr>
<tr>
<td>Attention (Thinking)</td>
<td>Decision (Intuiting)</td>
<td>Intention (Sensing)</td>
</tr>
<tr>
<td>(Where)</td>
<td>(When)</td>
<td>(What)</td>
</tr>
<tr>
<td>Direct</td>
<td>Sustained</td>
<td>Strong</td>
</tr>
<tr>
<td>Direct</td>
<td>Sustained</td>
<td>Light</td>
</tr>
<tr>
<td>Direct</td>
<td>Sudden</td>
<td>Strong</td>
</tr>
<tr>
<td>Direct</td>
<td>Sudden</td>
<td>Light</td>
</tr>
<tr>
<td>Indirect</td>
<td>Sustained</td>
<td>Strong</td>
</tr>
<tr>
<td>Indirect</td>
<td>Sustained</td>
<td>Light</td>
</tr>
<tr>
<td>Indirect</td>
<td>Sudden</td>
<td>Strong</td>
</tr>
<tr>
<td>Indirect</td>
<td>Sudden</td>
<td>Light</td>
</tr>
</tbody>
</table>

**Note.** The eight Basic-Effort-Actions examples taken from Laban for Animators: Overview of Laban Movement Analysis (Bistko, 2004, p.8).
Figure 4.1. The eight Basic-Effort-Actions: Press, Glide, Punch, Dab, Wring, Float, Slash, and Flick.

Note. The eight Basic-Effort-Actions movement sequences performed by Karen Studd, a Certified Laban Movement Analyst (C/LMA), a Professor at School of Dance, George Mason University, and a Program Coordinator and Master Teacher at Laban Institute of Movement Studies in New York, Manhattan. These movement sequences were videotaped on May 2013 at Intersection Digital Studio (IDS), Emily Carr University of Art and Design, Vancouver, CANADA. See these movement sequences in HD video format in Appendix A, section 1. © 2013 by Pattarawut Subyen and MovingStories Partnership.
4.2. Recognizing Movement Quality

In order to recognize and generate movement quality data, a real-time classifier supervised learning prototype called EffortDetect was used to recognize movement qualities from a moving body. EffortDetect is a movement quality recognition system that applies Laban Movement Analysis (LMA) using a supervised learning algorithm to classify movement qualities from a moving body in the form of Laban Basic-Efforts-Actions. EffortDetect was originally developed by the University of Illinois Institute for Advanced Computing Applications and Technologies and the university’s Dance Department, in collaboration with Dr. Thecla Schiphorst at Simon Fraser University’s School of Interactive Arts and Technology (Pietrowicz et al., 2010). The system was adapted and iterated through initial research by Diego Maranan, a Masters Degree student, under the supervision of Dr. Thecla Schiphorst and Dr. Philippe Pasquier at Simon Fraser University’s School of Interactive Arts and Technology (Maranan et al., 2014).

EffortDetect has two components: a wearable hardware accelerometer based system (Fig. 4.2 a) and a software system (Fig. 4.2 b). The hardware system is worn on a dancer’s wrist or used in the form of a glove. The wearable hardware system consists of an accelerometer, a microcontroller, and a radio transmitter that transmits a stream of acceleration data generated by the accelerometer. The software system is a classifier supervised learning\(^1\) system built using Max/Msp and the Weka Java API. The system was operated in a training phase and a real-time movement quality classification or recognition phase. In the training phase, the system was trained by Sarah Hook, a Laban Certified Movement Analyst and a Professor at the University of Illinois Urbana Champaign Dance Department. In this phase, a dancer wore the hardware system on the wrist and performed the eight Basic-Effort-Actions while the software performed continuous analysis of the acceleration data. The software system recorded movement data and used this data to form a movement quality classification model. In the real-time recognition phase, EffortDetect took the stream of acceleration data, translated it into a

\(^1\) Supervised learning, a machine learning algorithm, entails learning a mapping between a set of input variables X and an output variable Y and applying this mapping to predict the outputs for unseen data (Cord & Cunningham, 2008); see: Cord, M., & Cunningham, P. (2008). Machine Learning Techniques for Multimedia: Case Studies on Organization and Retrieval. Springer.
stream of extracted higher-level motion features, and then fed the motion features into a trained machine-learning system (Laban Effort Classifier) that recognized or classified patterns in the motion feature stream (Maranan, 2010; Maranan et al., 2014).}

Fig. 4.2. EffortDetect system diagram; (a) a wearable hardware system; (b) a software interface; (c) a stream of Basic-Effort-Actions vectors

EffortDetect outputted a stream of Basic-Effort-Actions vectors or a continuous stream of predictions and confidence values (Fig. 4.2 c) at a sampling rate of 100 samples per second. Each Basic-Effort-Actions vector movement profile consisted of nine float-number values between 0 and 1, representing the system’s confidence in a Basic-Effort’s presence in the movement (e.g., Dab=0.035, Flick=0.442, Float=0.025, Glide=0.00, Press=0.1201, Wring=0.016, Slash=0.0110, Punch=0.0451, Still=0.124 [see example in video format in Appendix A, section 1.2]). Still value represented the system’s confidence when a Basic-Effort was not present in the movement. Table 4.3 presents the example of a stream of Basic-Effort-Actions vectors for a 1-second gesture in which Punch Basic-Effort-Actions is targeted. A stream of Basic-Effort-Actions vectors was used in metaphoric mapping, computational data mapping, and the system design process to create visual representations of movement quality.

See: EffortDetect summary video in Appendix, section 1.1
Table 4.3. Example of a stream of Basic-Effort-Actions vectors for a 1-second gesture in which Punch Basic-Effort-Actions is targeted

<table>
<thead>
<tr>
<th>Profile number</th>
<th>Float</th>
<th>Punch</th>
<th>Glide</th>
<th>Slash</th>
<th>Flick</th>
<th>Wring</th>
<th>Press</th>
<th>Dab</th>
<th>Still</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.23769</td>
<td>0.68791</td>
<td>0.048718</td>
<td>0.028571</td>
<td>0.20721</td>
<td>0.07130</td>
<td>0.20769</td>
<td>0.12142</td>
<td>0.126</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>0.90847</td>
<td>0</td>
<td>0.726131</td>
<td>0</td>
<td>0.105601</td>
<td>0</td>
<td>0.26539</td>
<td>0.132</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>0.87990</td>
<td>0.023448</td>
<td>0.606131</td>
<td>0</td>
<td>0.337099</td>
<td>0</td>
<td>0.29052</td>
<td>0.126</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>99</td>
<td>0</td>
<td>0.99367</td>
<td>0</td>
<td>0.406444</td>
<td>0</td>
<td>0.227182</td>
<td>0</td>
<td>0</td>
<td>0.113</td>
</tr>
<tr>
<td>100</td>
<td>0</td>
<td>0.54376</td>
<td>0</td>
<td>0.383342</td>
<td>0</td>
<td>0.207766</td>
<td>0</td>
<td>0.10833</td>
<td>0.023</td>
</tr>
</tbody>
</table>

Note. See the example of a stream of Basic-Effort-Actions vectors in Appendix A, section 1.2.

An EffortDetect evaluation session was conducted with a dancer who has studied LMA as part of her university-level dance training as well as Cheryl Prophet, a certified Laban Movement Analyst, to help measure the system’s performance: the accuracy of the prediction (i.e., how accurately the system selected the dominant Basic-Effort-Action in a gesture from eight possible choices) and the confidence of the prediction (Maranan et al., 2014; Subyen et al., 2013). The system showed high accuracy and confidence values for Punch recognition, a strong tendency to confidently misclassify Slash as Punch, and strong Dab and Wring recognition accuracy but with low confidence. For a cumulative interpretation of the data stream, EffortDetect showed accuracy for recognition of the eight Basic-Effort-Actions as follows: Dab (80.97%), Flick (61.11%), Float (58.97%), Glide (78.78%), Press (55.55%), Punch (91.11%), Slash (62.5%), and Wring (76.67%). The system’s average accuracy was 70.71%.

For real-world application, EffortDetect’s wearable hardware system was used in a live performance of choreographer Trisha Brown’s piece, *Astral Convertible*, at the University of Illinois at Urbana Champaign. Dancers performed choreographic material that was accurately recognized by software built on the same backend as EffortDetect (Pietrowicz et al., 2010). EffortDetect was also successfully used in a series of interactive installations and live performances described in this thesis (See section 4.5.1 and section 4.5.3).
4.3. Metaphoric Mapping

Metaphor in linguistic perspective is the use of language to refer to something other than the original meaning in order to make connections between the two items or concepts (Knowles and Moon, 2006). Metaphor generally involves the cognitive process of understanding one domain of information in terms of another domain (Lakoff and Johnson, 1980). In contemporary visualization, there is a direct relationship between data-driven visualization and the cognitive process or creative mapping process discussed in metaphor theory (Cox, 2008). Cox adapted concepts from linguistic and visual metaphor to arrive at a framework for understanding visual metaphors in visualization context, called Visaphor³.

In the Visaphor framework, the mapping process is defined by having a source domain and a target domain. Both target and source domains constitute a system of beliefs or a concept network of ideas and assumptions about the collective imaginary within the domain (Cox, 2008; Indurkhya, 1992). We cognitively select characteristics from a concept network of the source domain and map these characteristics onto a concept network of the target domain. For instance, a cropped image of a Coca-Cola advertisement emphasizes a curve of the bottle that looks like the curve of a female body. The message of this advertisement suggests that most marketed beverages are high in calories, while the advertised beverage product has no calories. So, consumers will cognitively select an underlying similarity of characteristics between Coca-Cola (source domain) and the curve of a female body (target domain) and create mapping between source and target domains. Therefore, this mapping creates a new understanding of Coca-Cola in terms of a low-sugar diet beverage that will not make you fat.

This is an example of monomodal metaphors or metaphors whose target and source are exclusively rendered in one mode, called pictorial signs (Forceville and Urios-Aparisi, 2009, p. 24). According to Charles Forceville’s metaphor categorization, metaphors can be classified into eight different modes: (1) pictorial signs; (2) written

signs; (3) spoken signs; (4) gestures; (5) sounds; (6) music; (7) smells; and (8) touch. These eight different modes of metaphor are called multimodal metaphors (Forceville and Urios-Aparisi, 2009, p. 24).

In this project, I adopted Cox’s Visaphor framework (Cox, 2008a; 2008b) to explore the creative use and poetics of metaphoric mappings across modalities from human movement quality (gesture mode) to visualization (pictorial signs mode). This practice-based research used the Visaphor Framework as one component in the design process to create the visual representations of movement quality. Figure 4.3 presents a diagram of the Visaphor mapping process. In the Visaphor framework, the mapping process is characterized by twelve properties or characteristics described in Table 4.4.

Table 4.4. Characteristics of the Visaphor Framework (Cox, 2008)

<table>
<thead>
<tr>
<th>Visaphor Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visaphor is defined by having two parts: target domain and source domain.</td>
</tr>
<tr>
<td>Visaphor provides understanding of the target domain in terms of the source domain.</td>
</tr>
<tr>
<td>The target and source domains each represent an implication or conceptual system, also called a concept network.</td>
</tr>
<tr>
<td>A concept network includes collections of beliefs, concepts, symbols, technologies, cultural biases, assumptions, other metaphors, personal impressions, other property systems, and other worlds.</td>
</tr>
<tr>
<td>Properties or characteristics from the source domain are mapped onto the target domain.</td>
</tr>
<tr>
<td>This is not a one-to-one mapping; some characteristics get mapped, others do not.</td>
</tr>
<tr>
<td>This is not an arbitrary mapping; it has to make sense.</td>
</tr>
<tr>
<td>In this mapping, new meaning arises through novel association and contributes to target domain concept network.</td>
</tr>
<tr>
<td>Some visaphors have become embedded in culture so that we no longer recognize their metaphorical nature; they are interpreted as literal or conventional.</td>
</tr>
<tr>
<td>The metaphoric-content continuum ranges from conventional everyday visaphors to novel, figurative visaphors.</td>
</tr>
<tr>
<td>Aesthetics and creativity influence the position of visaphors on the metaphoric content continuum.</td>
</tr>
<tr>
<td>The audience interpretation depends on the context and the communication setting.</td>
</tr>
</tbody>
</table>
The Visaphor framework (1) provides a guideline for transforming data into visual forms and (2) describes the mappings (i.e., especially in the artistic visualization domain [see Chapter 2, section 2.2.2]) that are imaginative and ambiguous and which intend to facilitate the communication and meaning of the dataset. Visaphoric mappings of human movement have been reported in the literature. But few have used an artistic approach that relies jointly – as my approach does – on design-based thinking, attention to aesthetics, real-time system response, and a source domain of expertise-based knowledge about universal properties of movement. Bartram and Nakatani mapped low-level features of movement (e.g., amplitude, speed, direction, fluidity, and contour) generated by a single gesturing hand onto three types of affective impressions: positive valence, negative valence, and calm (Bartram and Nakatani, 2010). The mapping was derived through statistical analysis of qualitative feedback from users. While the work has substantial explanatory power in its production of the perception of visual motion, it is not concerned with our own focus of interactive artistic visualization.

Glow (Obarzanek and Weiss, 2008) is an interactive dance performance that uses interactive video technology to generate real-time responsive abstract graphics with sensual and grotesque qualities. While Glow’s visualization engine produces highly compelling and aesthetic results, it does not appear to use visaphoric principles, such as that of explaining one domain in terms of another. Better use of visaphoric mappings is made with some tools from Synchronous Objects (Palazzi et al., 2009), an interactive visualization toolkit that uses choreographic data to determine drawing parameters, such as direction, number of brushes, brush shape, brush size, and hue. The visualized data comprise choreographic information, such as the pattern of exchanges of choreographic cues, the number of dancers, and the distance between dancers. The closest example to my desired achievement is provided by Gutknecht et al., who created an interactive visual response to a Butoh dance performance (Gutknecht et al., 2008). Motion attributes such as intensity, direction, and flow were mapped to a circumplex space of affect, consisting of “pleasantness” and “activation.” These were then mapped to visualization parameters such as the size, colour, direction, and speed of visual elements. However, these mappings were designed to support the specific narrative of the performance and were not intended to reveal features that are independent of narrative and inherent in all movement, as LMA features are.
4.4. EMVIZ Visualization System Design

This section describes the system implementation, computation, and mapping process, and the system usage of a series of EMVIZ interactive artistic visualization engines – the L, Sketch, and Motion-Agent engines. The EffortDetect prototype described in section 4.3 was used to capture movement quality data and output a stream of Basic-Effort-Actions vectors to the EMVIZ visualization system. The visualization exploration research strategy described in Chapter 3 was used in the design process in order to experiment with different design strategies and computational techniques to reveal alternative design solutions. The Visaphor framework, LMA Effort Theory, and art and design theories were integrated with different computational algorithms to create design rules, colour palettes, and a meaningful visual representation of movement quality.

4.4.1. EMVZ (L) System

In this section, I detail the mapping strategy between movement quality (the eight Basic-Effort-Actions vectors) and generative visual elements, as well as colour style and colour palette. In applying Cox’s Visaphor framework in section 4.4, I define movement qualities as the source domain and line qualities as the target domain. Figure 4.4 summarizes the interpretative technique I employed in mapping characteristics of movement quality onto equivalent elements of visual design.

![Source Domain vs Target Domain](image-url)

Figure 4.4. The conceptual mapping from movement qualities (source domain) to line qualities (target domain)
The EMVIZ (L) system was developed using the Processing Development Environment with open source Java Processing Library, developed by Martin Prout. In order to create a visualization system that represented movement quality and responded in real time to movement, the EffortDetect system was integrated with EMVIZ (L), as mentioned in section 4.3. Figure 4.5 presents a system diagram of the EffortDetect and EMVIZ (L) system.

![System Diagram](image)

**Figure 4.5.** A system diagram of EffortDetect and EMVIZ (L) system; (a) The wearable sensor worn on a dancer’s wrist; (b) Components of the wearable hardware system; (c) EffortDetect software interface; (d) A stream of Basic-Effort-Actions vectors; (e) EMVIZ (L) system

### 4.4.1.1. Metaphoric Mapping

Each Basic-Effort’s parameters were mapped onto characteristics of lines in a way consistent with principles of two-dimensional design (Wong, 1972). Though simple, a line can convey meaning or emotion through characteristics of its visual form (Landa et al., 2006). A diagonal line can represent a feeling of motion and action. Round or curved lines can represent restfullness, while a short line can communicate a hurried feeling or nervousness. Thus, line characteristics can be metaphorically mapped onto the domain of the human body in motion. For instance, the forceful or vigorous quality of Strong Weight can be represented by a vertical line, while a diagonal line can convey Sudden Time. Figure 4.6 details my interpretive choices.
Figure 4.6. An example of visual representation for each Effort quality

4.4.1.2. Computation

To create visual representations of movement quality, the EMVIZ (L) design strategy is motivated by the desire to explore what generative computation can be applied with LMA Effort theory and how it can be utilized to generate visualization. In the generative computation literature, McCormack suggests that integrating generative grammar into the design process can produce a novel design structure and it allows artists or designers to explore a design solution space such as aesthetics, semiotics or culture (McCormack, 2004). Hence, I chose generative grammar as an approach and selected L-system generative grammar as a computational model to generate visualization. In computer graphics, L-system is a popular generative technique for simulating the growth process of plants, generating self-similar fractals or modelling the morphology of organisms.

Line qualities described in the previous section were used to determine generative drawing rules for an L-system engine that is at the heart of EMVIZ (L). First described by Lindenmayer in 1968, L-system is a string rewriting system that defines complex objects by successively replacing parts of a simple initial object using a set of rewritten rules or productions (Prusinkiewicz and Lindenmayer, 1990; Whitelaw, 2004). L-system interprets a string of characters as a linear sequence of instructions, generating graphics with an organic aesthetic (Prusinkiewicz and Lindenmayer, 1990). For instance, F can be defined as the symbol for the command, “Draw forward a step length of 10 pixels.” Plus (+) instructs the drawing procedure to turn right by 90 degrees. Thus, the command F+F+F+F would be interpreted as a command to draw a 10x10 square. This example describes the simplest type of L-system, called DOL (deterministic) L-system.
In this research project, however, I preferred less deterministic output visualization because the output from DOL L-system is always predictable. Therefore, I focused on the stochastic L-system. Similarly to DOL L-system, stochastic L-system interprets a string of characters as a linear sequence of instructions–but with multiple production rules. Each rule has a probability or weight parameter. The sum of all probabilities or weight parameters is equal to 1.0. For instance, F can be defined as the symbol for the command, “Draw forward a step length of 10 pixels.” Plus (+) instructs the drawing procedure to turn right by 90 degrees. Minus (-) instructs the drawing procedure to turn right by 90 degrees. Rules 1, 2, and 3 are defined as A, B and C, and assigned a symbol and a probability as follows: F+F (0.3), F-F (0.6), F+F-F (0.1). Thus, rule B with 0.6 probability (60%) is the most likely to produce the “F-F” command, while rule C with 0.1 probability (10%) has the smallest chance to produce the “F+F-F” command. Thus, applying the system with ABC rules three times can generate different combinations of symbols. Hence, applying the stochastic L-system with the visualization render engine will always produce different visualizations.

L-systems have been used by numerous artists, designers, and researchers as a generative process to create complexity with a series of simple yet cumulative rules. For instance, McCormack explored the use of L-system techniques in various ways to generate natural patterns or 3D plant animation, such as in *Turbulence* (1995), *Morphogenesis* (2001-2004) or *Bloom* (2006) (Whitelaw, 2004; McCormack, 2004). Hansmeyer examined how the logic of nature’s growth processes can function as a generator of architectural design and how L-systems can be applied to the production of architectural form (Hansmeyer, 2003). Hemburg explored the uses of L-system algorithms to generate surface and form for architectural design (O’Reilly and Hemberg, 2007). Similarly, I use an L-system algorithm in EMVIZ (L) to generate complex, abstract visual elements using sparse data. Figure 4.7 presents examples of six drawing rules for each Effort parameter generated by L-system.
In application, I created six L-system drawing rules for each Effort parameter based on visual representations described in Figure 4.7. According to stochastic L-system, each Effort parameter was assigned a probability or weight parameter to provide less deterministic output visualization. The combination of three L-system drawing rules created the design rules for each Basic-Effort-Action. For instance, the combination of Direct Space, Strong Weight, and Sudden Time created the Punch Basic-Effort-Action design rule. The L-system also has four main visual parameters: line length, line stroke, line rotation, and colour palette. The length, rotation, and stroke of line visual elements were mapped onto values taken from a stream of Basic-Effort-Actions vectors. Figure 4.8 shows the algorithm flowchart for the EMVIZ (L) visual generation process.
The EMVIZ (L) interface was composed of four main views: still value and a set of eight Basic-Effort-Actions visualizations and associated confidence values (Fig. 4.9 a); a visualization of the primary or dominant Basic-Effort-Actions (Fig. 4.9 b); text that displayed the dominant or primary Basic-Effort-Actions, updated every 10 milliseconds (Fig. 4.9 c); and a dynamically updated histogram representing the confidence values for each Basic-Effort-Action (Fig. 4.9 d).
Figure 4.9.  EMVIZ (L) visualization system interface; (a) Still value and a set of eight Basic-Effort-Actions visualizations and the confidence value; (b) A visualization of dominant Basic-Effort-Actions; (c) The dominant or primary Basic-Effort-Actions text display; (d) A dynamically updated histogram representing the confidence values for each Basic-Effort-Action

4.4.1.3.  Colour Mapping

The line elements were rendered in colour by applying a model inspired by Kandinsky’s theory of colour (Kandinsky, 1977). Kandinsky, a Russian painter and theorist, is known for introducing the concept of abstraction to painting through his use of colour “mapping” techniques. Kandinsky explored the harmonious relationship between sound and colour, and used musical terms to describe his painting process (Kandinsky, 1977). Kandinsky proposed that colour communicates an inner expression, emotion or idea to the spectator – much as Laban proposed that movement quality is an indicator of inner physical attitude. For instance, sudden, urgent or quick movement can be conveyed with red, yellow or orange. I adapted Kandinsky’s colour model to the system’s drawing parameters, resulting in a subjective and expressive use of colour in my mappings (Fig. 4.10).
The colour palette for each Basic-Effort-Action was selected based on the detected input of dominant value in a stream of Basic-Effort-Actions vectors. For instance, the system will randomly select colour in the Punch colour palette if the Punch Basic-Effort-Action vectors value is detected as the dominant Effort in a stream of Basic-Effort-Actions vectors.

### 4.4.1.4. Result and System Usage

To see the system performance in real time, a pilot study session was conducted on May 2010. The pilot feedback session involved an audience composed of a mix of various experts from the fields of computer science, dance, visual arts, archaeology, and scientific visualization. In this pilot session, I presented the mapping design process, system implementation, and algorithm underpinning the visualization system. I then asked a dancer with university-level LMA training to repeatedly and in random sequence perform movements demonstrating each Basic-Effort-Action. Generative visualizations that responded in real time to the sensed movement of the dancer were simultaneously generated, displayed, and projected by EMVIZ (L). Figure 4.11 shows the pilot feedback session held in the School of Interactive Arts and Technology Interactivity lab / Blackbox on May 21st 2010.
Figure 4.11. EMVIZ (L) pilot study session on May 21st 2010

Audience feedback described the aesthetic qualities of the visualizations as “beautiful” and “nice.” However, they felt that the mapping process was arbitrary because the mappings were abstract selections. However, the relationship between states of movement, such as quickness and strength, could be recognized. They reported that the manifestation of movement could be seen in some Basic-Effort-Actions visualizations (e.g., Float or Glide), but were unable to explain how. However, some audience members commented that the visualizations were too complex and fast, and the graphic too small. They were unable to recognize Directness or Indirectness because of the richness and complexity of visual forms. They were unable to differentiate different Effort qualities because simultaneous changing of shape of line and motion caused cognitive overload. Figure 4.12 shows sample outputs from EMVIZ (L) for each of the eight Basic-Effort-Actions as they were performed by the dancer in the pilot study session.
Figure 4.12. EMVIZ (L)’s visaphoric approach to visualizing movement quality: Laban’s eight Basic-Effort-Actions represented through a poetic and communicative mapping to colour and visual forms

Note. See more EMVIZ (L) visualizations videos and images in Appendix A, section 2.
This prototype of the EMVIZ (L) system was presented as an interactive installation called *Paint with your Efforts*, during an e-mixer event at the Surrey Art Gallery in British Columbia, Canada on May 28th 2010. Figure 4.13 shows sample images from the exhibition. In order to create an interactive experience, I invited event attendees to use a glove equipped with the EffortDetect wearable hardware system to interact with the visualization system and to move with various qualities while guided by a video demonstration illustrating the concept of motion qualities and LMA Basic-Effort-Actions.

![EMVIZ (L) interactive art installation at Surrey art gallery](image)

*Note.* See more images and other materials of installation in Appendix A, section 2.

The audience reported being able to see the correspondence between visual movement representations and the movements themselves. They provided feedback on the aesthetic qualities of the visualizations and described them as “beautiful and evocative,” citing aesthetic unity as a particularly strong feature. They reported that the visualizations helped their ability to detect and interpret changes in the qualitative aspects of the dancer’s movement, and to connect them with the dancer’s own experience of movement quality. Direct, Indirect, Sudden, Light, and Strong Effort parameter values were particularly legible in the visualization.

However, not all Effort qualities were equally legible to the audience. For example, the correlation between Sustained Time and its visual counterpart was not
always recognizable. Also, the audience felt that the appearances and transitions between visual elements may move too quickly to be fully appreciated. A transition between two different Basic-Efforts may be useful to address this problem. Finally, they reported that the complexity of the visualizations could be reduced somewhat and the graphics enlarged in order to highlight individual differences between visualizations.

Many of these issues could be quickly resolved by adjusting the drawing rules and parameters, while preserving the conceptual framework of the mappings. For instance, the animation speed could be adjusted by changing the animation’s frame rate setting. The rules could be modified to reduce the visual complexity of line elements. Other issues, such as finding a way to transition between two Basic-Effort-Actions, will require exploration into computational techniques for interpolating between visual representations of two different Basic-Effort-Actions.

The EMVIZ (L) system was presented as a 20-minute oral presentation at the Digital Resources for the Humanities and Arts (DRHA) conference at Brunel University, London in September 2010 (See Appendix A, section 2 [Publications/DRHA_presentation.pdf]) and exhibited as a poster at the 6th Annual IRMACS Day at Interdisciplinary Research in the Mathematical and Computational Sciences Center, Simon Fraser University in April 2011 (See Appendix A, section 2 [Publications/Irmacs_poster.pdf]). It was also published as a research paper at the International Symposium on Computational Aesthetics in Graphics, Visualization, and Imaging in August 2011 (See Appendix A, section 2 [Publications/Conference_paper.pdf]).
4.4.2. **EMVIZ (Sketch) System**

In this section, I describe the second iteration of the EMVIZ visualization system, called Sketch. I detail the mapping strategy between movement quality (the eight Basic-Effort-Actions vectors) and visual generation, as well the colour model and palette. To design EMVIZ (Sketch), I used different approaches from EMVIZ (L) to explore the metaphoric mapping process. In applying Cox’s Visaphor framework in section 4.4, EMVIZ (L) mapped the characteristics of Effort parameters to the characteristics of the elements of visual design. In contrast to EMVIZ (L), the Sketch system used the characteristics of the eight Basic-Effort-Actions as the source domain, rather than Effort parameters, and the characteristics of the eight Basic-Effort-Actions visual composition as the target domain. The Sketch system was developed using the Processing Development Environment. In order to create a visualization system that represented movement quality and responded in real time to movement, the EffortDetect system was integrated with the Sketch system in the same way that it was used with the previous EMVIZ (L) system.

4.4.2.1. **Metaphoric Mapping**

To explore the creative use and poetics of metaphoric mappings for EMVIZ (Sketch), I employed the method that artists (e.g., Cubists, Expressionists, Futurists or Abstract expressionists) use for carrying movement or conveying movement in painting to create visual compositions based on the Fine Arts principles of visual elements and composition (Gottlieb, 1958). These methods include the use of unstable visual elements (e.g., a diagonal line or a triangle shape) to convey an impression of movement, the use of elements that move toward or away from another element or the use of elements that attract and hold the viewer’s attention (e.g., irregular shape, saturated colour, diagonal or linear direction, and oversize object). I applied these methods to create visual composition (the target domain) for the metaphoric mapping process. To obtain the characteristics of the target domain, abstract visual forms and compositions of the eight Basic-Effort-Actions were created, analyzed, and described based on my observation and experiences in theory and practice in the communication design and visual art discipline. This process was divided into four tasks: observation, sketching, analyzing, and describing. Figure 5.14 (a) presents the artistic activities and outcomes of the process for generating visual composition or the characteristics for the eight Basic-Effort-Actions (target domain).
<table>
<thead>
<tr>
<th>Observation</th>
<th>Sketching</th>
<th>Analyzing</th>
<th>Describing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observe a dancer with university-level LMA training performing the eight</td>
<td>Sketch a dancer's gesture and capture the essence of movement quality</td>
<td>Apply the principles of visual composition and analyze each Basic-Effort-Action sketch based on visual communication and visual art theory</td>
<td>Summarize and describe how each of selected principle of visual composition can be used for represent movement quality</td>
</tr>
<tr>
<td>Basic-Effort-Actions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Experience, idea, and note about the characteristics of the eight Basic-Effort-Actions based on personal observation</td>
<td>Abstract visual forms and compositions for each Basic-Effort-Actions</td>
<td>Personal reflection about which principles of visual composition can be used for representing movement quality</td>
<td>The characteristics of visual representation for the eight Basic-Effort-Actions based on principles of visual composition, personal observations, and personal experiences</td>
</tr>
</tbody>
</table>

**Figure 4.14.** Sketch Process. (a) The process for generating the characteristics of visual representation for the eight Basic-Effort-Actions (the target domain); (b) The sketches of abstract visual forms and compositions of the eight Basic-Effort-Actions

First, I observed a dancer with university-level LMA training performing repeatedly in random sequence movements that embodied each Basic-Effort-Action. In this observation, I experienced different movement qualities and developed ideas for incorporating the principles of visual communication to represent movement quality. Then I applied various artistic methods for conveying movement in painting by sketching a dancer’s gestures and trying to capture the essence of movement quality after observing the dancer’s performance of the eight Basic-Effort-Actions. This resulted in representing each Basic-Effort-Action as abstract visual forms and compositions. Figure 4.14 (b) presents the sketches of abstract visual forms and compositions derived from observation and sketching tasks.
In the third step, I analyzed the abstract visual forms and compositions sketches based on visual communication and visual art theory. The outcomes of this stage are my personal reflections about which principles were suitable for describing each Basic-Effort-Action. For instance, the use of simple shapes (e.g., dot, line or circle) that quickly or slowly change the size (grid proportion) of concentric visual structure can be used to convey directness, quickness, lightness or strength. Finally, I created a short description of the characteristics of each Basic-Effort-Action or movement quality based on the principles of visual communication and my personal observation and experiences. Table 4.5 presents the sketches and characteristics of the eight Basic-Effort-Actions derived from the sketch process.

Table 4.5. The Characteristics of the eight Basic-Effort-Actions

<table>
<thead>
<tr>
<th>BEAs</th>
<th>Sketch</th>
<th>Characteristics of the eight Basic-Effort-Actions derived from sketch process</th>
</tr>
</thead>
<tbody>
<tr>
<td>Press</td>
<td><img src="image" alt="Press Sketch" /></td>
<td>Circles slowly change the size from small to big while moving outward from centre and slowly dissolve in background within a concentric visual structure</td>
</tr>
<tr>
<td>Glide</td>
<td><img src="image" alt="Glide Sketch" /></td>
<td>Circles slowly move from lower left to upper right or from lower right to upper left and slowly dissolve in background within a linear diagonal grid structure</td>
</tr>
<tr>
<td>Punch</td>
<td><img src="image" alt="Punch Sketch" /></td>
<td>Circles quickly change the size from small to big, radiate outward from centre, and quickly dissolve in background within a concentric visual structure</td>
</tr>
<tr>
<td>Dab</td>
<td><img src="image" alt="Dab Sketch" /></td>
<td>Circles appear in random position, quickly radiate from the centre, and quickly dissolve in background within a concentric visual structure</td>
</tr>
<tr>
<td>Wring</td>
<td><img src="image" alt="Wring Sketch" /></td>
<td>Lines spiral slowly towards centre within a spiral and concentric visual structure and dissolve in background</td>
</tr>
<tr>
<td>Float</td>
<td><img src="image" alt="Float Sketch" /></td>
<td>Circles slowly move upward and slowly dissolve in background within curve grid structure</td>
</tr>
<tr>
<td>Slash</td>
<td><img src="image" alt="Slash Sketch" /></td>
<td>Lines quickly move in all directions (up, down, left, right) and quickly dissolve in background within linear diagonal grid structure</td>
</tr>
<tr>
<td>Flick</td>
<td><img src="image" alt="Flick Sketch" /></td>
<td>Circles quickly radiate from the centre upward left or right and quickly dissolve in background within a radiating visual structure (centre of radiation in off-centre position)</td>
</tr>
</tbody>
</table>
A certain shape and principle of visual structure can convey meaning through structural characteristics. For instance, circles that slowly change in size from small to big, move outward from the centre, and dissolve within a concentric visual structure, can represent a sense of Press (Direct space, Sustained time, and Strong weight). A sense of Punch (Direct space, Sudden time, and Strong weight), on the other hand, can be created by the use of circles that quickly change in size from small to big, radiate outward from the centre, and suddenly dissolve into the background within a concentric visual structure. Thus, the eight Basic-Effort-Actions characteristics described by Rudolf Laban can be metaphorically mapped onto the domain of shape and visual structure derived from the sketch process.

4.4.2.2. Computation

EMVIZ (L) uses generative L-system algorithm to generate visual representations of movement quality. The results show that L-system computation is very useful in the metaphoric mapping process and it is a good candidate for generating aesthetic visualization. However, the system encountered several problems for representing movement quality, such as the complexity of visual forms, the visual transition between two different Basic-Effort-Actions and difficulties in representing some Effort parameters (e.g., Indirect, Light or Sustained). Thus there are pros and cons for representing the eight Basic-Effort-Actions using L-system algorithms. The Sketch system, on the other hand, used a simple computation design instead of generative computation to generate visualization. The characteristics of the eight Basic-Effort-Actions derived from the Sketch process were used to create the computation for generating visual representations of movement quality.

To create computation for the Sketch system, I referenced natural phenomena, events or daily activities in the characteristics of the eight Basic-Effort-Actions described in Table 4.5. This connected the conceptual metaphoric mapping to an easily understood concept for designing Sketch system computation. For instance, circles that quickly radiate weightlessly from the center and then suddenly dissolve into the background within a concentric visual structure can be compared to a ripple effect, such as when an object is dropped into water. Circles wandering slowly upward and dissolving into the background within a curved grid structure can be compared to floating
soap bubbles. Table 4.6 compares the characteristics of the eight Basic-Effort-Actions to natural phenomena, events or daily activities.

Table 4.6. Basic-Effort-Actions characteristics in comparison to natural phenomena, events or daily activities

<table>
<thead>
<tr>
<th>The characteristics of the eight Basic-Effort-Actions derived from metaphoric mapping</th>
<th>Natural phenomena, events or daily activities</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Press:</strong> Circles linger linearly outward from centre, slowly increase in size, and dissolve in background within a concentric visual structure</td>
<td>Pushing something across the horizontal plane</td>
</tr>
<tr>
<td><strong>Glide:</strong> Circles move from lower left to upper right or from lower right to upper left, and dissolve in background within a linear diagonal grid structure</td>
<td>Aerial locomotion (gliding flight) in birds or insects</td>
</tr>
<tr>
<td><strong>Punch:</strong> Circles radiate forcefully outward from centre, quickly increase in size, and suddenly dissolve in background within a concentric visual structure</td>
<td>Explosion (releasing of energy)</td>
</tr>
<tr>
<td><strong>Dab:</strong> Circles radiate quickly and weightlessly from centre and suddenly dissolve in background within a concentric visual structure</td>
<td>Water ripple</td>
</tr>
<tr>
<td><strong>Wring:</strong> Lines slowly move toward centre within a spiral and concentric visual structure and dissolve in background</td>
<td>Spiral patterns or texture in nature</td>
</tr>
<tr>
<td><strong>Float:</strong> Circles move upward slowly and weightlessly, and dissolve in background within curved grid structure</td>
<td>Floating soap bubbles</td>
</tr>
<tr>
<td><strong>Slash:</strong> Lines move quickly and diagonally (up, down, left, right) and suddenly dissolve in background within linear diagonal grid structure</td>
<td>Swinging motion from playground swing</td>
</tr>
<tr>
<td><strong>Flick:</strong> Circles radiate quickly from the centre upward (left or right) and suddenly dissolve in background within a radiation visual structure (centre of radiation in off-centre position)</td>
<td>Snapping something off with the fingers</td>
</tr>
</tbody>
</table>

In application, EMVIZ (Sketch) used a simple particle system to simulate visual representations of movement quality. The particle system had four main parameters (position, velocity, rotation, and gravity) and seven visual parameters (number, size, stroke weight, colour palette, colour saturation, and colour opacity). These visual parameters were mapped onto values taken from a stream of Basic-Effort-Actions vectors. For instance, high Basic-Effort-Actions values (e.g., Punch=1.0) increase particle velocity, size, stroke weight or colour saturation, while low Basic-Effort-Actions values (e.g., Punch=0.7) decrease particle velocity, size, stroke weight or colour saturation. Figure 4.15 shows an algorithm flowchart for the EMVIZ (Sketch) visual generation process.
The EMVIZ (Sketch) interface design is similar to the EMVIZ (L) system, except for the data recorder and data player module. The Sketch interface was composed of five main views, (1) still value and a set of eight Basic-Effort-Actions visualizations and the confidence value (Fig. 4.16 a); (2) a visualization of the dominant Basic-Effort-Actions (Fig. 4.16 b); (3) text that displayed the dominant Basic-Effort-Actions, updated
every 10 milliseconds (Fig. 4.16 c); (4) a dynamically updated histogram representing the confidence values for each Basic-Effort-Actions (Fig. 4.16 d); and (5) a data module that recorded and played back a stream of Basic-Effort-Actions vectors (Fig. 4.16 e). This interface was designed to support EffortDetect system evaluation and allow data to be recorded for further analysis (see section 4.5.2.4).

![Figure 4.16. EMVIZ (Sketch) visualization system interface: (a) Still value and a set of eight Basic-Effort-Actions visualizations and the confidence value; (b) A visualization of dominant Basic-Effort-Actions; (c) The dominant or primary Basic-Effort-Actions text display; (d) A dynamically updated histogram representing the confidence values for each Basic-Effort-Actions; (e) A data recorder and data player module](image)

4.4.2.3. Colour Mapping

The shape and visual structures in motion were rendered in colour by applying the elements of colour theory and twelve-pointed colour described by Johannes Itten (Itten, 1970). Itten, a Swiss Expressionist painter, teacher, and theorist associated with the Weimar Bauhaus, is known for his instruction of general rules, psychological perception, and aesthetic of colour or the elements of colour theory. In the previous EMVIZ (L) system colour mapping, I had applied Kandinsky’s colour model, which is very poetic and interpretative colour usage based on his art practice and synesthetic
experiences. In EMVIZ (Sketch) colour mapping, I relied instead on Itten’s elements of colour because it was systematically created and designed to educate artists or art students, rather than based solely on his personal experiences. Itten’s colour theory is also a well-known basic colour theory used in art instruction. Itten built on the works of other colour experts (e.g., Goethe, Bezold, Chevreul, and Hözel) and his theory described the characteristics of colour effect and the expressive use of colour (Itten, 1970).

Itten defined colour into 12 types – red, yellow, blue, red-orange, orange, yellow-orange, yellow, yellow-green, green, blue-green, blue, blue-purple, and purple. Yellow is the lightest, while purple is the darkest colour (hue). These two colours are the strongest light-dark contrast and thus were placed on opposite axes in Itten’s twelve-pointed colours. Red-orange and blue-green, on the other hand, are the warmest and coldest colours. In cold-warm contrast, cold colours are purple, blue-purple, blue, blue-green, green, and yellow-green, while warm colours are red-purple, red, red-orange, orange, yellow-orange, and yellow. However, blue-green, red-orange, and a shade between them can be considered cold or warm colours depending on the percentage of black or white mixed in or on the tones (colder or warmer) they compare with. Cold colour properties can be metaphorically defined as transparent, airy, far or light, while warm colour properties can be verbalized in terms such as stimulant, dense, near or heavy (Itten, 1970).

In the EMVIZ (L) colour mapping process, the colours were assigned to six Effort parameters and for each Basic-Effort-Action, three Effort parameters were combined to create a colour palette. Sketch system, on the other hand, mapped cold-warm colour properties to three Effort parameters’ characteristics rather than mapping each colour characteristic to each Effort parameter. In this mapping, warm colour properties (e.g., stimulant, dense, near or heavy) were mapped with attitudes of resisting or fighting associated with three Effort parameters: Direct, Strong, and Sudden. Cold colour properties (e.g., airy, far or light) were mapped with attitudes of accepting or indulging associated with three Effort parameters: Indirect, Light, and Sustained. As a result, purple, blue-purple, blue, blue-green, green, and yellow green were mapped and described as Indirect, Light, and Sustained. Red-purple, red, red-orange, orange, yellow-orange, and yellow were mapped and described as Direct, Strong, and Sudden. Again, blue-green, red-orange, and a shade between them can be either cold or warm, and
therefore Indirect, Light, and Sustained or Direct, Strong, and Sudden. Figure 4.17 (a) presents the mapping between cold-warm colour properties and Laban Effort parameters.

**Figure 4.17.** EMVIZ (Sketch) colour mapping: (a) The mapping between cold-warm colour properties and Laban Effort parameters; (b) Eight colour palettes for the eight Basic-Effort-Actions
Basic-Effort-Actions. In this mapping, Press, Glide, Wring, and Float were categorized by cold colours while Punch, Dab, Slash, and Flick were categorized by warm colours. The cold-warm colours were mixed with different percentages of black and white to create the eight Basic-Effort-Actions colour palette (15 hues per colour palette), described as follows:

(1) *Press* colour palette used shades of purple (cold) to represent Sustained Effort parameter characteristics, while shades of red-purple (warm) were used to represent the characteristics of Direct and Strong Effort parameters;

(2) *Glide* colour palette used shades of blue-green and lightest blue (cold) to represent Light and Sustained Effort parameter characteristics, while shades of lightest yellow-green (warm) were used to represent the characteristics of Direct Effort parameter;

(3) *Punch* colour palette used shades of red, dark red-orange, and light red-purple (warm) to represent Direct, Strong, and Sudden Effort parameter characteristics;

(4) *Dab* colour palette used shades of red-purple and dark-red (warm) to represent Direct and Sudden Effort parameter characteristics while shades of lightest purple (cold) were used to represent the characteristics of Direct Effort parameters;

(5) *Wring* colour palette used shades of blue and light blue-purple (cold) to represent Indirect and Sustained Effort parameters characteristics, while the darkest blue (warm) was used to represent Strong Effort parameter characteristics;

(6) *Float* colour palette used shades of green, blue-green, lightest green, and light yellow-green (cold) to represent Indirect, Light, and Sustained Effort parameters characteristics;

(7) *Slash* colour palette used shades of orange and yellow-orange (warm) to represent Strong and Sudden Effort parameters characteristics and lightest red-purple (cold) to represent the characteristics of Indirect Effort parameters; and

(8) *Flick* colour palette used shades of green and yellow-green (cold) to represent Light and Indirect Effort parameters characteristics, while yellow and light
yellow-orange (warm) were used to represent the characteristics of Sudden Effort parameters.

In colour computation, hue and colour values were assigned to each Basic-Effort, while saturation was mapped onto values taken from the stream of Basic-Effort-Actions vectors. For instance, high Punch value (i.e., Punch=1.0) created high saturation of red, red-orange, and light red-purple, while low Punch value (i.e., Punch=0.5) created lower saturation of red, red-orange, and light red-purple.

4.4.2.4. Result and System Usage

EMVIZ (Sketch) was used in the EffortDetect system evaluation session. The system was developed to make the output of EffortDetect or a stream of Basic-Effort-Actions visually legible during the evaluation session. Session participants included a dancer who had studied LMA as part of her university-level dance training and a certified Laban Movement Analyst to help measure the system’s performance – that is, the accuracy of the prediction (i.e., how accurately the system selected the dominant Basic-Effort in a gesture from among eight possible Basic-Efforts) and the confidence of the prediction (Maranan et al., 2014; Subyen et al., 2013).

In the evaluation session, the dancer performed all eight Basic-Effort-Actions and the movement analyst worked with the dancer to ensure that the dancer was performing the Basic-Effort-Actions to a degree that was legible to the analyst. The Sketch system visualized a stream of the eight Basic-Effort-Actions in real time. The visualization allowed the movement analyst to visually compare the Basic-Effort-Actions performed by a dancer and the eight Basic-Effort-Actions being recognized by the EffortDetect system. Figure 4.18 (a) presents EMVIZ (Sketch) in EffortDetect during this evaluation session.

In this evaluation, we used EMVIZ (Sketch) custom function built in Max/MSP to record 80 Basic-Effort profile streams generated during the blind and transparent testing components. We collected a total of 109 movement profile streams, composed of 14 Dab, 18 Flick, 13 Float, 11 Glide, 12 Press, 15 Punch, 16 Slash, and 10 Wring streams (Maranan et al., 2014; Subyen et al., 2013). I examined Basic-Efforts movement profile streams and selected the best representative profile streams for each Basic-Effort. EMVIZ (Sketch) used these profile streams to generate eight visual representations of movement quality, presented in Figure 4.18 (b).
Figure 4.18. EMVIZ (Sketch) system usage and output visualization: (a). EMVIZ (Sketch) in an EffortDetect evaluation session; (b) Visual representations of movement quality generated by EMVIZ (Sketch).

Note. See visualizations video in Appendix A, section 3.
4.4.3. **EMVIZ (Motion-Agent) System**

In this section, I describe the EMVIZ visualization system's third iteration, called Motion-agent. In EMVIZ (L) and EMVIZ (Sketch system), the metaphoric mapping and colour mapping process relied on visual communication theory and my personal experiences. In EMVIZ (Motion-Agent), however, I incorporated the results from empirical research in affective motion texture (Lockyer and Bartram, 2012; Lockyer et al., 2011) within the design process, rather than relying solely on existing theory and my experiences. In applying Cox's Visaphor framework described in section 4.4, I defined movement quality as the source domain and motion pattern characteristics as the target domain. I detailed mapping strategy between movement quality (the eight Basic-Effort-Actions vectors) and generative motion patterns, as well as the colour model and colour palette. EMVIZ (Motion-Agent) was developed using Max/Msp Programming Environment and the open source Boids Library called jit.boids3d, developed by Eric Singer, Jasch, André Sier, and Wesley Smith. Figure 4.19 presents a system diagram of EffortDetect and the Motion-Agent system.

![System Diagram](image)

**Figure 4.19.** A system diagram of EMVIZ (Motion-Agent) system: (a) The wearable hardware system; (b) EffortDetect software interface; (c) EMIVZ (Motion-Agent) software interface; (d) Visualization output from system

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EMVIZ (Motion-agent) was originally called EMVIZ (Flow). The system was named for flow dance performance (see section 4.534). However, Flow is also the name of Laban Effort parameters that was not used in the eight Basic-Effort-Actions (see section 4.2). To make the system name clearer, I changed it from "Flow" to "motion-agent" according to the computation name for generating visualization.
4.4.3.1. Metaphoric Mapping

The parameters for each Basic-Effort-Action were mapped onto characteristics of different motion patterns in a way consistent with the results from affective motion textures research. In this research, Lockyer et al. (2012) explored how motion properties contribute to affective impressions. The results from this empirical research show that even simple variations of motion properties (e.g., path curvature, speed, direction or shape) can create or elicit different affective impressions (Lockyer and Bartram, 2012; Lockyer et al., 2011). Figure 4.20 presents the example of dot visual element with four different affective motion textures, as described by Lockyer et al.

![Figure 4.20. Affective motion textures](image)


Through simple shapes, different movement types can convey meaning or emotion through their motion patterns. Fast, intense, dense, focused and straight forceful lines or dots with linear, radial or random motion toward the centre can represent a sense of drive with force. In contrast, calm, light, and linear lines or dots with a random motion toward upper right, left or centre can communicate a feeling of movement in a liquid environment or the air. Slow, focused, forceful, and straight lines or dots with linear motion outwards from the centre can represent a feeling of movement by weight or force in a certain direction. Slow, focused, radial, and wavy lines or dots with radial or spiral motion towards or outwards from the centre can communicate twisted or compressed movement.

Thus, motion pattern can be metaphorically mapped onto the domain of the human body in motion. For instance, the forceful, focused, and quick qualities of Strong Weight, Direct Space, and Sudden Time can be represented by fast, intense, and focused lines or dots moving with linear, radial or randomly moving patterns toward the
centre. In contrast, calm, focused, and slow lines or dots moving with linear motion to upper right or left can convey Light Weight, Direct Space, and Sustained Time. This interpretive mapping choice resulted in the description of motion pattern and shape for the eight Basic-Effort-Actions (Table 4.7).

Table 4.7. The eight Basic-Effort-Actions and associated motion patterns and shapes

<table>
<thead>
<tr>
<th>BEAs</th>
<th>Motion Pattern and Shape</th>
</tr>
</thead>
<tbody>
<tr>
<td>Press</td>
<td>Slow, focused, forceful, and straight lines or dots with linear motion outward from centre</td>
</tr>
<tr>
<td>Glide</td>
<td>Calm, focused, soft, and slow lines or dots with linear motion toward upper right or left</td>
</tr>
<tr>
<td>Punch</td>
<td>Fast, intense, dense, focused, and straight forceful lines or dots with linear, radial or random motion towards centre</td>
</tr>
<tr>
<td>Dab</td>
<td>Calm, focused, soft, and quick lines or dots with radial motion inward towards centre</td>
</tr>
<tr>
<td>Wring</td>
<td>Slow, focused, radial, and wavy lines or dots with radial or spiral motion toward or outward from centre</td>
</tr>
<tr>
<td>Float</td>
<td>Calm, light, and linear lines or dots with a random motion toward upper right, left or centre</td>
</tr>
<tr>
<td>Slash</td>
<td>Fast, intense, spiraling, radial, and forceful lines or dots with linear or random motion outward to upper right-left-up-down</td>
</tr>
<tr>
<td>Flick</td>
<td>Calm, light, spiraling, and radial, lines or dots with linear or radial motion outward to upper back right or left</td>
</tr>
</tbody>
</table>

4.4.3.2. Computation

The EMVIZ (Motion-Agent) system used a computational model of autonomous agents-based system to generate visual representations of movement quality. Agent-based system is a field of study examining the emergent behaviour of populations of artificial agents, which can be used as a process for generating graphical representations of data (Hutzler et al., 2000). Agent-based system has been researched and experimented with by artists, designers, and researchers as a method for representing information in the visualization domain. For instance, Hutzler et al. presented computer-generated artwork that generated abstract visual representations of meteorological data (e.g., temperature, rain, clouds or wind direction) using multi-agent systems (Hutzler et al., 2000). Moere developed a flocking agents technique that represented complex time-varying datasets through visually recognizable formations and motion typologies (Moere, 2004). Milam and Pasquier presented an ambient visualization system that used autonomous flocking agents to visualize student population fluctuation on a university campus (Milam and Pasquier, 2008). Bisig et al.
created a series of audio-visual and interactive dance visualization artworks using artificial autonomous agent systems or swarm agents to generate visualization responding to human movement (Besig and Unemi, 2009). Agent-based system, therefore, is not a new visualization generation technique and it has been extensively used in research and artistic projects. However, to the best of my knowledge, there has been little research in using agent-based system to represent human movement information.

Thus, I used agent-based system (i.e., autonomous flocking agents) as a technique in EMVIZ (Motion-Agent) to generate visual representations of movement quality. This raises the question of how agent behaviour can be designed to generate different motion patterns (emergent patterns of behaviours) that convey or represent movement quality information. To generate visual representations of movement quality, the EMVIZ (Motion-Agent) system used a computational model of autonomous agents, called Boids (bird-like object). The Boids system simulates artificial agent motion behaviours (i.e., flocking behaviour) based on realistic representations of animal behaviour, such as flocks of birds, schools of fish or animal herds (Reynolds, 1987). In the Boids system, every agent is capable of wandering around their world seeking a target at specific locations, steering to avoid other agents, steering towards the average heading of other agents, and steering towards the average position of other agents (Reynolds, 1987). When agents interact with each other, the complexity of agent motion patterns emerges. These motion patterns can be computed based on a set of simple rules and the parameters of the simulated flocking agent can be optimized to create different types of motion patterns. Table 4.8 presents the 14 Boids computational parameters defined in EMVIZ (Motion-Agent) system implementation.
Table 4.8. Boids computational parameters and description

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Num</td>
<td>Number of agents</td>
</tr>
<tr>
<td>Neighbours</td>
<td>Number of neighbours each boids consults when flocking</td>
</tr>
<tr>
<td>Accel</td>
<td>Strength of neighbour speed matching instinct</td>
</tr>
<tr>
<td>Speed</td>
<td>Overall speed</td>
</tr>
<tr>
<td>Max/Min Speed</td>
<td>Maximum and minimum speed in speed range</td>
</tr>
<tr>
<td>Match</td>
<td>Strength of neighbour speed matching instinct</td>
</tr>
<tr>
<td>Avoid</td>
<td>Strength of neighbour avoidance instinct with nearby flockmates</td>
</tr>
<tr>
<td>Attract</td>
<td>Strength of attraction to point of attraction</td>
</tr>
<tr>
<td>Align</td>
<td>Alignment instinct with nearby flockmates</td>
</tr>
<tr>
<td>Prefdist</td>
<td>Preferred distance from neighbours</td>
</tr>
<tr>
<td>Repel</td>
<td>Strength of object avoidance instinct</td>
</tr>
<tr>
<td>Dist</td>
<td>Vision distance to avoid objects (wall)</td>
</tr>
<tr>
<td>Internia</td>
<td>Willingness to change speed and direction</td>
</tr>
</tbody>
</table>

My mapping design process was explored by transforming metaphoric mapping to computation and experiment with the adjustment of Boids computational parameter values. First, I divided each parameter into High, Medium, and Low values. Each parameter consisted of defined sets of float-number values between 0.1 and 30.0. High parameter values ranged between 21.0 and 30.0, Medium parameter values between 11.0 and 20.9, and Low parameter values between 0.1 and 10.9. Specific combinations of High, Medium, and Low values for each Boids computational parameter created certain types of motion pattern. I specified the range of each Boids parameter value and created eight predefined parameters for the eight Basic-Effort-Actions. These predefined parameters were mapped to a stream of Basic-Effort-Actions vectors. For example, Table 4.9 shows a specific combination that creates a sense of drive with Force, Thrust or Punch Basic-Effort-Actions design rule.

Table 4.9. Example of specific combination of Boids computational parameter values for Punch Basic-Effort-Actions design rule.

<table>
<thead>
<tr>
<th>Parameter Ranges</th>
<th>Boids Parameters with range of specific value</th>
</tr>
</thead>
<tbody>
<tr>
<td>High (21-30)</td>
<td>Max Speed (22.0) Accel (25.0) Internia (26.0) Repel (27.0) Speed (21.0)</td>
</tr>
<tr>
<td>Medium (11-20.9)</td>
<td>Attract (15.0) Align (11.0) Min Speed (11.0)</td>
</tr>
<tr>
<td>Low (0.1-10.9)</td>
<td>Match (5.0) Prefdist (7.0) Dist (7.0) Avoid (9.0) Neighbours (1)</td>
</tr>
</tbody>
</table>

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This approach used combinations of different High, Medium, and Low Boids computational parameter values with a specific range for each parameter value to create eight Basic-Effort-Actions design rules for generating visualisation of movement quality. Figure 4.21 presents the mapping from metaphoric mapping process to Boids computational parameters to create the eight Basic-Effort-Actions design rules.

<table>
<thead>
<tr>
<th>Motion Pattern and Shape</th>
<th>Boids Computational Parameters</th>
<th>Parameter Exploration</th>
<th>Basic-Effort Design Rules</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slow, focused, forceful, and straight lines or dots with linear motion outward centre</td>
<td>Neighbours: number of neighbours each boids conflicts when flocking</td>
<td>Experiment with Adjusting Boids Computational Parameter Values and Define Specific Range of Each Parameter</td>
<td>Press</td>
</tr>
<tr>
<td>Calm, focused, soft, and slow lines or dots with linear motion toward upper right or left</td>
<td>Accel: acceleration or deceleration rate</td>
<td>Strong + Direct + Sustained</td>
<td>Glide</td>
</tr>
<tr>
<td>Fast, intense, dense, focused, and straight forceful lines or dots with linear, radial, or random motion toward centre</td>
<td>Match: Strength of neighbour speed matching instinct</td>
<td>Light + Direct + Sustained</td>
<td>Punch</td>
</tr>
<tr>
<td>Calm, focused, soft, and quick lines or dots with radial motion inward centre</td>
<td>Avoid: Strength of neighbour avoidance instinct with nearby flockmate</td>
<td>Strong + Indirect + Sustained</td>
<td>Dab</td>
</tr>
<tr>
<td>Slow, focused, radial, and wavy lines or dots with radial or spiral motion toward outward from centre</td>
<td>Attract: Strength of attraction to point of attraction</td>
<td>Light + Direct + Sudden</td>
<td>Wiring</td>
</tr>
<tr>
<td>Calm, light, and linear lines or dots with a random motion toward upper right, left or centre</td>
<td>Align: Alignment instinct with nearby flockmates</td>
<td>Light + Indirect + Sudden</td>
<td>Float</td>
</tr>
<tr>
<td>Fast, intense, spiraling, radial, and forceful lines or dots with linear or radial motion outward upper right-left-up-down</td>
<td>Prefdist: Preferred distance from neighbours</td>
<td>Strong + Indirect + Sudden</td>
<td>Slash</td>
</tr>
<tr>
<td>Calm, light, spiraling, and radial, lines or dots with linear or radial motion outward upper back right or left</td>
<td>Dist: Vision distance to avoid objects</td>
<td>Light + Indirect + Sudden</td>
<td>Flick</td>
</tr>
<tr>
<td>Acceleration Strength and Deceleration Rate</td>
<td>Speed: Overall speed</td>
<td>Experiment with Adjusting Boids Computational Parameter Values and Define Specific Range of Each Parameter</td>
<td>Pressure</td>
</tr>
<tr>
<td>Willingness to Change Speed and Direction</td>
<td>Max/Min: Maximum or minimum speed of speed range</td>
<td>Adhesion and Cohesion</td>
<td></td>
</tr>
</tbody>
</table>

Figure 4.21. The mapping from Boids computational parameters to create the eight Basic-Effort-Actions design rules

EMVIZ (Motion-Agent) used Open Graphics Library (OpenGL) to render each autonomous flocking agent in a form of quad primitive shape, a four-sided polygon similar to a rectangle. Quadrilateral size was mapped onto values taken from a stream of Basic-Effort-Actions vectors. For instance, high Basic-Effort-Actions value (e.g., Punch=1.0) created a large-sized quadrilateral, while low Basic-Effort-Actions value (e.g., Punch=0.5) created a smaller sized quadrilateral. To make autonomous flocking agents look less geometric, custom-made abstract texture was designed and mapped onto the quad primitive shapes. From a visual perception perspective, objects rendered using smooth texture, angle or curve can be more pleasant and create a sense of serenity than shapes with hard angles (Halper et al., 2003; Hevner, 1935; Mono (1997) cited from Taylor and Mandryk, 2012). Figure 4.22 compares the visualization output from the system without texture and with mapped texture.
EMVIZ (Motion-Agent) was not only implemented as an interactive screen-based visualization system but also as an interactive visualization that responded in real time to movement in dance performance. To use the system in dance performance, the Microsoft Kinect tracking hardware system was incorporated with EffortDetect to track the dancer's arm gesture. The tracking system allowed the dancer to control the movement direction of autonomous flocking agents or visual representations of human movement qualities. This allowed the viewer to see the association between the direction of the dancer's gestural motion and the direction of visualization. Figure 4.23 presents the integration of EffortDetect, Microsoft Kinect tracking hardware system, and EMVIZ (Motion-Agent) system in an interactive visualization dance performance called Flow (see section 4.5.3.4).

The EMVIZ (Motion-Agent) interface was composed of four main views: an EffortDetect control panel (Fig. 4.24 a), a Kinect interface (Fig. 4.24 b), an agent controller (Fig. 4.24 c), and a visualization window (Fig. 4.24 d). The EffortDetect control panel is composed of a real-time updated histogram representing the confidence values
for each Basic-Effort-Action, a data recorder recording a stream of Basic-Effort-Actions vectors, and a data reader that playbacks recorded Basic-Effort-Actions data. The Kinect interface is composed of a data receiver receiving a stream of arm position data from the Kinect sensor, a data recorder recording a stream of arm position data, and a data reader to playback the recorded data stream. The agent control panel is composed of a Boids parameters controller, a camera control panel, a colour mapping interface, and a Basic-Effort-Actions design rule panel. Figure 4.24 (e) shows other components under the hood of the EMVIZ (Motion-Agent) system. Figure 4.25 presents the algorithm flowchart for the EMVIZ (Motion-Agent) visual generation process during a live dance performance.

Figure 4.24. EMVIZ (Motion-Agent) system interface; (a) EffortDetect control panel; (b) Kinect interface; (c) Agent control panel; (e) Other system components
Figure 4.25. EMVIZ (Motion-Agent) algorithm flowchart in dance performance

Note. Software is written in Max/Msp.

4.4.3.3. Colour Mapping

In mapping movement quality to colour, I encountered the problem of subjectivity because few researchers explored the relationships between the perception of different movement qualities (i.e., the eight Basic-Effort-Actions) and colour. However, some empirical research projects have described the relationships between emotion perception and human-body movement. For instance, some emotions were found in the
whole body posture and its movement quality (Wallbott, 1998, cited in Kipp and Martin, 2009). Distinct emotions are often associated with different qualities of body movement, such as the amplitude, speed, and fluidity of movement (Pollick et al., 2001). High movement activity or high speed, velocity, and acceleration of body movement can create a sense of excitement or arouse multiple emotions, while low movement dynamics can create a sense of sadness or low intensity (Atkinson et al., 2004). In colour psychology, the darker or more saturated a colour is, the more it connotes “forcefulness,” while the more hue a colour has, the more it connotes “calmness” (Wright and Rainwater, 1962). Several researchers have explored the relationships between colour and emotion and suggested that colour can communicate an inner expression or emotion to the viewer (Clarke and Costall, 2008; Hevner, 1935; Kaya and Epps, 2004; Picard, 2000; Simmons, 2006; Taylor and Mandryk, 2012; Valdez and Mehrabian, 1994). For instance, warm colours (e.g., red, orange or purple-red) were associated with excited or enraged feelings while cool colours (e.g., green or blue) were associated with calmness or low anxiety (Clarke and Costall, 2008).

To effectively map between colour and human movement quality, I grounded my colour mapping on human movement quality, emotion perception, and the colour psychology theories described above. I adopted Goethe’s primary colour circle and Itten’s colour wheel, and adapted them using my own subjective criteria and the results from colour and emotion research to the design colour scheme for the eight Basic-Effort-Actions. This colour scheme was based on primary, secondary, and tertiary colours (red, red-orange, orange, yellow-orange, yellow, yellow-green, green, blue-green, blue, blue-purple, purple, and red-purple) described in the colour models developed by Goethe and Itten. I used this colour scheme as a model for describing colour characteristics, associated with emotions and characteristics of movement quality, and used them with EVIZ (Motion-Agent) drawing parameters (Fig. 4.26 a).

In EVIZ (Motion-Agent) colour computation, the colour scheme was applied with the HSV (hue, saturation, and value) colour model to create eight colour spectrums for the eight Basic-Effort-Actions (Fig. 4.26 b). Hue and colour values were assigned to each Basic-Effort-Action, while saturation was mapped onto values taken from the stream of Basic-Effort-Actions vectors. For instance, high Punch value (i.e., Punch=1.0) created high saturation of red, while low Punch value (i.e., Punch=0.5) created lower
saturation of red. Figure 4.26 presents my subjective and expressive use of colour for the eight Basic-Effort-Actions.

<table>
<thead>
<tr>
<th># BEAs</th>
<th>From Colour Meaning to Movement Quality Characteristics</th>
<th>Colour Scheme</th>
<th>Colour Spectrum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Press</td>
<td>Power, Nobility, Ambition, Stability, Active</td>
<td>Focus, Straight, Undeviating, Forceful, Leisurely, Lingering</td>
<td>Purple</td>
</tr>
<tr>
<td>Glide</td>
<td>Comfort, Calm, Faithful, Determination</td>
<td>Focus, Straight, Indulging in time, Easily overcoming gravity</td>
<td>Blue &amp; Blue-Green</td>
</tr>
<tr>
<td>Punch</td>
<td>Anger, Aggressive, Intense, Active</td>
<td>Forceful, Powerful, Fast, Focus, Straight</td>
<td>Red &amp; Red-Orange</td>
</tr>
<tr>
<td>Dab</td>
<td>Excitement, Energy, Emotional</td>
<td>Focus, Straight, Undeviating, Weightless, Buoyant, Urgent</td>
<td>Red -Purple</td>
</tr>
<tr>
<td>Wring</td>
<td>Calm, Powerful, Comfort</td>
<td>Forceful, Powerful, Flexible, Spiraling, Slow, Lingering</td>
<td>Blue-Purple</td>
</tr>
<tr>
<td>Float</td>
<td>Calm, Neutral, Peaceful</td>
<td>Buoyant, Wandering, Deviating, Slow, Lingering</td>
<td>Green</td>
</tr>
<tr>
<td>Slash</td>
<td>Joy, Excited, Warmth, Dynamic, Energetic</td>
<td>Fast, Energetic, Active, Wandering, Deviating</td>
<td>Orange &amp; Yellow-Orange</td>
</tr>
<tr>
<td>Flick</td>
<td>Neutral, Excited, Comfortable</td>
<td>Weightless, Wandering, Deviating, Quick, Urgent</td>
<td>Yellow &amp; Yellow-Green</td>
</tr>
</tbody>
</table>

Figure 4.26. The Basic-Effort-Actions colour mapping; (a) Colour meaning, movement quality characteristics, and colour scheme for the eight Basic-Effort-Actions; (b) The eight Basic-Effort-Actions colour spectrum

4.4.3.4. Result and System Usage

To examine the EMVIZ (Motion-Agent) system’s performance, I asked a LMA-trained dancer\(^5\) to wear the hardware sensor glove and perform all eight Basic-Effort-Actions.

\(^5\) Kristin Carlson, a dancer who has studied LMA as part of her university-level dance training.
Actions. We videotaped the dancer’s performance and designed custom function for recording the Basic-Effort-Actions vectors stream generated by the glove’s sensor. The dancer performed the eight Basic-Effort-Actions in the following sequence: press, glide, punch, dab, wring, float, slash, and flick. The Basic-Effort-Actions vectors stream and associated arm position data were recorded in real time. I recorded eight videos of the dancer’s performance, capturing Basic-Effort-Actions vectors streams and arm position data for 64 movement profiles, with eight stream profiles for each Basic-Effort. I examined Basic-Efforts movement profile streams and selected the best representative profile streams for each Basic-Effort-Action. EMVIZ (Motion-Agent) used these profile streams to generate eight visual representations of movement quality, presented in Figures 4.27 and 4.28.
Figure 4.27. Punch, Slash, Dab, and Flick visualizations generated by EMVIZ (Motion-Agent).

Note. See visualizations video in Appendix A, section 4.
Figure 4.28. Press, Wring, Float, and Glide visualizations generated by EMVIZ (Motion-Agent)

*Note.* See visualizations video in Appendix A, section 4.
The EMVIZ (Motion-Agent) application was used in Flow, an improvisational dance performance at the Emily Carr University of Art and Design in Vancouver, Canada during a Conference on Human Factors in Computing Systems (CHI) 2011 workshop on the theme of “the user in flux”: bringing HCI and digital arts together to interrogate shifting roles in interactive media (Fig. 4.29 a). During Flow, movement qualities were extracted from the performer’s body and the resulting visualizations projected onto the floor. At the end of the performance, I invited the audience to use a glove equipped with the EffortDetect hardware system to interact with EMVIZ (Motion-Agent). EMVIZ (Motion-Agent) was also exhibited at Simon Fraser University Surrey’s Community Open House 2011. In this event, we again encouraged the audience to use the EffortDetect glove to interact with EMVIZ (Motion-Agent) and move with various qualities while guided by the authors and a dancer describing the concept of movement qualities and LMA Effort (Fig. 4.29 b). The EMVIZ (Motion-Agent) system was also presented as a 20-minute oral presentation and published as a research paper at the Electronic Visualization and the Arts conference in London on August 2013 (See Appendix A, section 4 [Publications/Eva_London_2013_paper.pdf]).
Figure 4.29. EMVIZ (Motion-Agent) system usage; (a) Flow: Interactive Dance Performance at CHI 2011 workshop; (b) EMVIZ (Motion-Agent) system at Simon Fraser University Open House 2011 event

Note. See more images and other materials of interactive dance performance in Appendix A, section 4.
4.5. Conclusion

EMVIZ is a visualization engine that represents my exploration in design process and metaphoric mappings between movement qualities – in the form of Laban Basic-Effort-Actions – and dynamic abstract visualization. Three EMVIZ visualization systems (L, Sketch, and Motion-Agent) used different approaches in metaphoric mapping, computational modelling, and colour mapping technique. The resulting visual representations reflect aesthetic choices made in generative processes, design rules, and colour styles. These choices were grounded in a theoretical framework for representing knowledge across modalities from a non-visual physical movement domain (gesture) to a visual domain (pictorial sign).

In this chapter, I have described (1) the EMVIZ visualization systems (L, Sketch, and Motion-Agent) design process, (2) how I experimented with conceptual mapping and transformed it into a computational approach using the L-system, simple particle system, and Boids agent system, and (3) how I chose an expressive use of colour for representing and generating movement quality visualizations. The three EMVIZ visualization systems have been used in interactive installations, movement recognition system evaluations, and interactive dance performances. First, EMVIZ (L) was used in an interactive art installation at Surrey Art Gallery during which the audience provided critical feedback regarding their response to the aesthetic and communicative properties of the visualizations. Second, EMVIZ (Sketch) was used as a visual dashboard during the EffortDetect system evaluation at the School of Interactive Arts and Technology Interactivity lab / Blackbox. EMVIZ (Sketch) allowed the output of EffortDetect to be visually legible during the evaluation session. Both the dancer and the movement analyst used EMVIZ (Sketch) to cross-reference with the eight Basic-Effort-Actions performed by the dancer. Third, the EMVIZ (Motion-Agent) system was used and incorporated with Microsoft Kinect tracking hardware system in an interactive dance performance during the CHI 2011 workshop and exhibited as an interactive system showcase at the SFU Open House 2011. Table 4.10 compares the different aspects of EMVIZ (L), EMVIZ (Sketch), and EMVIZ (Motion-Agent) system designs.
Table 4.10. Comparison among three different aspects of EMVIZ systems design

<table>
<thead>
<tr>
<th>EMVIZ Source</th>
<th>Metaphoric Mapping Target</th>
<th>Mapping Approach</th>
<th>Computation</th>
<th>Colour Mapping</th>
<th>System Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>L Movement Quality (Effort Parameter Characteristics)</td>
<td>Element of Visual Design (Line Characteristics)</td>
<td>Based on principle of Two-Dimensional Design</td>
<td>L-System</td>
<td>Kadinsky's Model</td>
<td>Interactive Installation</td>
</tr>
<tr>
<td>Sketch Movement Quality (The eight Basic-Effort-Actions Characteristics)</td>
<td>Visual Representation of the eight Basic-Effort-Actions Derived from Sketch Process (Visual Composition Characteristics)</td>
<td>Based on Principles of Visual Communication and My Personal Observation / Experiences</td>
<td>Eight different computation</td>
<td>Itten's Model</td>
<td>Visual Dashboard for EffortDetect Evaluation</td>
</tr>
<tr>
<td>Motion-Agent Movement Quality (The eight Basic-Effort-Actions Characteristics)</td>
<td>Motion Pattern Characteristics</td>
<td>Referred from Affective Motion Texture Research and also Based on My Design Experiences</td>
<td>Boids System (Flocking Agent)</td>
<td>Goethe's and Itten's Model</td>
<td>Interactive Dance Performance</td>
</tr>
</tbody>
</table>

EMVIZ exemplifies an approach to artistic visualization that privileges embodied design processes and artistic metaphoric mappings in generating sensory output from analytical movement frameworks developed from movement expertise, in order to support greater democratization of shared understanding of human movement. The EMVIZ framework represents a strategy for bridging Laban Effort theory with my artistic design process in mapping data to meaning, applying meaning to computation, and connecting colour with motion to create dynamic visual representations of human movement quality. Finally, I believe that the three developed EMVIZ artistic visualization systems can be useful in other areas, such as designing for attention and non-verbal communication in mobile devices, constructing meaningful interaction in public and urban spaces or as designing tools to support teaching Laban Effort theory (See future research in Chapter 8).
Chapter 5.

Evaluation and Data Analysis

This chapter presents the evaluation process of three different versions of the EMVIZ visualization system (L, Sketch, and Motion-Agent) and describes the research hypothesis, participant selection, experimental design, study materials and procedure, and statistical data analysis. The study results are presented primarily in quantitative form and they were used as evidence to support the comparative analysis process in Chapter 7.

The goal of this study is to evaluate the communicative ability of the three versions of the EMVIZ visualization system in conveying movement quality through abstract expressive animations or visualizations. Thus, the evaluation process addressed the following questions:

**RQ1.** Are the eight Basic-Effort-Actions visualizations among systems equally able to communicate the movement quality they are supposed to convey? In other words, is there a difference among systems in correct matching between Basic-Effort-Actions movement sequences and Basic-Effort-Actions visualizations? If there is a significant difference, which visualization among systems is significantly different and performs better than the others?

**RQ2.** Are participants able to equally recognize and identify Effort parameter values that are supposed to represent each Basic-Effort-Action visualization? In other words, is there a difference among systems in correct identification of Effort parameter values (Space, Weight, Time) for each Basic-Effort-Action visualization? If there is a significant difference, which Effort parameter (Space, Weight, Time) is significantly different and performs better than others?
RQ3. Are the three EMVIZ visualization systems equally able to communicate the movement quality and Effort parameter values they are supposed to convey? In other words, is there a difference among systems in mean number for correct matching of Basic-Effort-Actions visualizations and correct Effort parameter values identification?

H₁ = Alternative Hypothesis, H₀ = Null Hypothesis. The hypotheses were:

RQ1: H₁, There is a difference in percentage of correct matching between Basic-Effort-Actions movement sequences and Basic-Effort-Actions visualizations among systems for each Basic-Effort-Action visualization with respect to their p-values (probability).

RQ2: H₁, There is a difference in percentage of correct Effort parameter values identification among systems with respect to their p-values (probability).

RQ3: H₁, There is a difference in mean number for (1) correct matching between Basic-Effort-Actions movement sequences and Basic-Effort-Actions visualizations and (2) Effort parameter values identification, with respect to their p-values (probability).

5.1. Participants

Certified Movement Analysts (CMA) who studied and received certification at the LABAN/BARTENIEFF Institute of Movement Studies (LIMS)—an accredited institutional member of the National Association of Schools of Dance (NSAD)—were chosen to participate in a study to evaluate three different versions of the EMVIZ visualization system. According to the Laban/Bartenieff Institute (Laban/Bartenieff Institute, 2009), a CMA:

- Has knowledge of Laban Movement Analysis and understands how it is applied within various fields and contexts.
- Has been evaluated in their ability to physically demonstrate and verbally articulate concepts related to Body, Effort, Shape, Space, and Relationship, from both broad and specific perspectives.
- Has demonstrated the ability to verbally articulate and physically demonstrate the basic principles of Bartenieff Fundamentals sm, and
understands their relationship to LMA—both theoretically and practically.

- Has the ability to apply theory in practice through research and creative work.
- Has an understanding of their own movement style in a variety of contexts, including interaction.
- Has experience observing, recording, and reading movement data using motifs, phrase writing, coding sheets, video, and live observation.

We chose CMAs as participants for this study because of their expertise in theory and practice in Laban Movement Analysis Effort (LMA Effort) theory. In statistical contexts, this is called a “self-selected” survey that helps increasing important in establishing the validity of the survey data (Lazar et.al 2010, p.108). Since most participants lived outside of Canada, online surveys were used to evaluate three different versions of the EMVIZ visualization system (see section 5.3.3).

Participants were recruited via personal email invitation through Dr. Thecla Schiphorst and Karen Bradley, Executive Director and Director of Research of Laban/Bartenieff Institute of Movement Studies in New York City (see section 5.4). The study was carried out via online survey. Participants were informed of study details and procedures, as well as participation risks through an online participant consent statement (see Appendix B, section 5). They were informed that they were allowed to quit the study at any time (see section 5.4). Upon completion of the survey, participants received a $20 Amazon Gift Card via email.

5.2. Study Design

We began by designing an online survey system that enabled participants to evaluate the visualizations generated by three different versions of the EMVIZ visualization systems. In designing the experiment, it was important to make sure that (1) LMA Effort was a consistent and accurate framework to classify recognizable movement qualities and (2) all CMAs (participants) had consistent and accurate

1 See study limitations in Chapter 8, section 8.41
2 This study design aims to validate only eight movement qualities or the eight Basic-Effort-Actions in postural effortful actions, not gestural actions of one body part or free movement
observational ability to identify the Basic-Effort-Actions\textsuperscript{2} in movement sequences. It was necessary to validate both the LMA Effort framework and the ability of trained CMAs in the experiment, although the LMA Effort framework is a well-respected theory and CMAs are known for their expertise in theory and practice in the LMA framework. If the LMA Effort framework and CMAs' observational skills in recognizing or identifying eight movement qualities in movement sequence are inaccurate and inconsistent, then the CMAs will not be able to accurately evaluate the communicative ability of EMVIZ visualization systems. This process helped to make evaluation results valid and consistent. It also helped generate the ground truth about the validity of LMA and CMA when the LMA framework and CMA expertise are used for developing computational models or system evaluation in other research fields such as gesture recognition, robotic expression, and movement classification. Thus, we divided the study into two sections: LMA validation and EMVIZ evaluation.

The LMA validation section aimed to:

1. Validate the consistency and accuracy of the LMA Effort Framework to codify recognizable movement qualities, specifically the Basic-Effort-Actions in postural effortful actions.

2. Validate the ability of trained CMAs to identify the eight Basic-Effort-Actions (in postural effortful actions) in short movement sequences performed by a trained CMA dancer.

In this session, participants were first asked to watch a series of videos depicting movement qualities (Basic-Effort-Actions) performed by a dancer and then match the video to one of the eight Basic-Effort-Actions (see section 5.3.3). Then participants were asked to watch a dancer perform the eight Basic-Effort-Actions within a Diagonal Scale\textsuperscript{3} and then identify the order (sequence) of the eight Basic-Effort-Actions in the movement.

\textsuperscript{3} Diagonal Scale is the notion Rudolf Laban used for describing movement in extremes of far-reaching space that crisscross the body's centre from one corner of a three-dimensional movement cube to the opposite corner. Diagonal scale is used to explore these extremes of personal space and often used by actors to warm up and practice a full range of active energies (Bradley 2008), see: Bradley, K. K. (2008). Rudolf Laban (Routledge Performance Practitioners). Routledge.
sequence. These two tasks help to validate the LMA Effort framework and the ability of CMAs to recognize and evaluate Effort qualities.

In the second section, the EMVIZ evaluation aimed to evaluate the communicative ability of three different versions of the EMVIZ visualization system (L, Sketch, and Motion-Agent) to convey the eight Basic-Effort-Actions through abstract expressive animations or visualizations. All three versions of the visualization system used the same input movement data captured from the trained CMA dancer (see section 5.5). In this session, participants were asked to watch a series of videos depicting visual representations of movement quality (Basic-Effort-Actions) generated by the three system iterations based on the movement of the dancer and match the visualization to one of eight Basic-Effort-Actions (see section 5.5.3).

In the evaluation design, we chose a within-subject experiment design that involved each participant performing under all sets of conditions in the study (Cairns and Cox, 2008; Lazar et al., 2010). All participants were asked to evaluate EMVIZ (L), EMVIZ (Sketch), and EMVIZ (Motion-Agent) visualization systems and, in the last part of the study, provided overall feedback of the three systems. We chose the within-subject experiment because it allowed researchers to more easily monitor the effect upon individuals and individual differences were less likely to influence study results (Cairns and Cox 2008). We designed a survey feature that allowed participants to save data at any time and return to the survey later. This allowed participants to take a rest when they felt tired or their interest flagged.

We randomized the order of the movement and visualization videos because of the matching nature of questions (Figure 5.8, 5.9, 5.10). Each movement matched up with exactly one visualization, which meant that as participants worked their way through the movements, there were fewer and fewer visualizations left to choose from. Thus, the first movement has eight possible choices of visualizations and the last has only one possible choice. While the participant could change their mind, it was possible that the order in which they proceeded would affect the answers. Thus, we randomized the order of the movement and visualization videos to minimize possible unreliable research results.
5.3. Study Materials

To conduct the evaluation session, study materials were prepared during the Movingstories May Residency research workshop, an eight-day residency that brought Movingstories researchers (computer scientists, artists, and CMAs) together to facilitate brainstorming around developing computational models for meaningful movement interaction (Fig. 5.1). On May 24th 2013, we conducted a session where session participants observed and recorded LMA Basic-Effort-Actions with a motion capture system at the Intersection Digital Studio (IDS), Emily Carr University of Art and Design (Vancouver, Canada).

For the workshop session, we also asked Karen Studd—a Certified Laban Movement Analyst (CMA) and Professor at the George Mason University’s School of Dance and Program Coordinator and Master Teacher at the Laban Institute of Movement Studies in New York, Manhattan—to attach the hardware sensor on her wrist (Fig. 5.1 a) and perform the eight Basic-Effort-Actions (Fig. 5.1 b). We videotaped her performance and designed custom software for recording the Basic-Effort-Actions vectors stream generated by the wearable sensor. First, Studd performed the eight Basic-Effort-Actions (four times per Basic-Effort-Action) one by one in the following sequence: Float, Punch, Glide, Slash, Dab, Wring, Flick, and Press. The Basic-Effort-Actions vectors stream data were recorded in real time. We recorded a total of 32 videos and captured Basic-Effort-Actions vectors streams data for 32 movement profiles, with four stream profiles for each Basic-Effort-Action. Then Studd performed the eight Basic-Effort-Actions in a continuous sequence within the Diagonal Scale (Float, Punch, Glide, Slash, Dab, Wring, Flick, and Press) four times and we videotaped these movement sequences. Table 5.1 summarizes all collected data used in the study materials preparation session, and Figure 5.1 shows images from the session.
Table 5.1. All collected data from the study materials preparation session

<table>
<thead>
<tr>
<th>Study Section</th>
<th>Data</th>
<th>Format</th>
</tr>
</thead>
<tbody>
<tr>
<td>LMA Validation</td>
<td>32 videos of the eight Basic-Effort-Actions (Four videos per Basic-Effort-Actions)</td>
<td>HD Video</td>
</tr>
<tr>
<td></td>
<td>Two videos of the eight Basic-Effort-Actions within Diagonal Scale</td>
<td>HD Video</td>
</tr>
<tr>
<td>EMVIZ evaluation</td>
<td>32 Basic-Effort-Actions movement profiles (Four stream profiles for each Basic-Effort-Actions)</td>
<td>Text File</td>
</tr>
</tbody>
</table>

Note. See all captured data during study preparation session in Appendix B, section 1.

Figure 5.1. A study preparation session at movingstories May residency workshop: (a) The hardware sensor attached to a dancer’s wrist; (b) A dancer performs the eight Basic-Effort-Actions; (c) Discussions after recording session

Note. See https://www.flickr.com/photos/movingstories/sets/72157633773103776/page3/

5.3.1. Data Observation

To use the data collected from the study preparation session, we first examined video footage of the eight Basic-Effort-Actions movement sequences and then edited and grouped them into eight categories, with four videos per Basic-Effort-Action for each category. After reviewing all video clips, we found that some Basic-Effort-Actions were not crystallized or in postural effortful actions according to LMA Effort theory. Therefore, we asked two CMAs to choose the clearest of each Basic-Effort-Actions video for each Basic-Effort-Action category. Secondly, we reviewed four videos of the eight Basic-
Effort-Actions within the Diagonal Scale and chose only one video per Basic-Effort-Action, because we found they equally represented the eight Basic-Effort-Actions. Thus, we used a total of eight videos of the eight Basic-Effort-Actions movement sequences and one Diagonal Scale video per Basic-Effort-Action in the LMA validation section.

For the EMVIZ evaluation session and in order to explore data, we created a simple bar chart visualization in Java processing sketch that visualized the eight Basic-Effort-Actions movement profile streams (see BEA_Chart.java in Appendix B, section 1). Figure 5.2 shows the Punch Basic-Effort-Action bar chart visualization, which represents four Punch Basic-Effort profile streams in association with four Punch Basic-Effort-Action videos.

![Figure 5.2. Bar chart visualization representing four Punch Basic-Effort-Action profile streams in association with four Punch Basic-Effort-Action videos](image)

We selected each Basic-Effort-Action profile stream according to the eight Basic-Effort-Actions videos selected by two CMAs. Thus, each Basic-Effort-Action movement profile stream is associated with each Basic-Effort-Actions video selected by the CMAs. All three versions of the visualization system used the same input movement data or movement profile streams captured from the trained CMA and dancer to generate eight visual representations of movement qualities.
5.3.2. Visualization Generation

To prepare visualization materials for the EMVIZ evaluation session, we used the eight Basic-Effort-Actions movement profile streams as the input data for EMVIZ (L), EMVIZ (Sketch), and EMVIZ (Motion-Agent). In EMVIZ (L) and EMVIZ (Sketch), we fed each Basic-Effort-Action movement profile stream to the visualization system, observed the output visualization, specified the frame rate at 30 frames per second, and used the saveFrame function in Java processing to save the visualization into a numbered sequence of images. After rendering all visualizations, we combined a numbered sequence of images for each Basic-Effort-Action in Adobe After Effects and rendered all visualizations into a video format at 30 frames per second. In EMVIZ (Motion-Agent), the same process was applied except that jit.qt.record Jitter object was used to save each Basic-Effort-Actions visualization into the video format at 30 frames per second. A total of 24 Basic-Effort-Actions visualization videos were created, with eight videos per EMVIZ system.

To summarize, the materials used in the survey consisted of (1) eight Basic-Effort-Actions movement sequence videos performed by the trained CMA dancer, (2) eight Basic-Effort-Actions within the Diagonal Scale video, and (3) 24 Basic-Effort-Actions visualization videos generated by EMVIZ (L), EMVIZ (Sketch), and EMVIZ (Motion-Agent), with eight visualizations per EMVIZ system. To prepare the online survey, all videos were uploaded to a video-sharing website called vimeo.com. The eight Basic-Effort-Action movement sequence videos were renamed to movement sequence 1-8, while the Basic-Effort-Actions visualizations were renamed to “visualization 1-8.” The eight Basic-Effort-Actions within the Diagonal Scale video was renamed to “movement sequence” (see Appendix B, section 2).

5.3.3. Online Survey Questionnaire

To create the online survey, we used a free open-source application written in PHP based on MySQL, called LimeSurvey. The LimeSurvey system was installed on the web server called movement.iat.sfu.ca hosted by the School of Interactive Arts and Technology, Simon Fraser University. The default template was modified to a custom design function that suited all evaluation tasks. The survey had seven pages and was divided into five parts. The first page described study details, research aims, evaluation
tasks, and data collection, and included a consent statement (Fig. 5.3). The second page was a registration page requesting information on email address, gender, age, level of education, occupation, year, and location where participants obtained CMA certification, additional certification, level of movement expertise, and LMA usage (Fig. 5.4). The third page contained study Part1 (LMA Validation). The fourth, fifth, and sixth pages contained study Part2, Part3, and Part4 (EMViZ System A, B, and C evaluation) respectively. The seventh page was the overall feedback and the last page of the survey.
You are invited to participate in a research survey conducted by Pat Subyen, a Ph.D student at Simon Fraser University, under the guidance of faculty supervisors, Dr. Philippe Pasquier and Dr. Thecla Schiphorst.

As a participant of this study you will help to validate LMA knowledge illustrated through observation and analysis skills. In the survey, you will be asked to complete two tasks described below:

1) **Identify the LMA Basic-Effort-Actions:**
   In this first task, you will be asked to view 8 short video recordings of a trained CMA and dancer performing one of the Basic-Effort-Actions (BEA) and after each of the 8 shorts clips, associate the video with the label (or name) of that Basic-Effort-Action (BEA). You will be asked to view and identify each of the eight Basic-Effort-Actions described by Rudolf Laban.

2) **Evaluate a set of 8 visualizations (for each of System A, System B and System C) that represent each of the Basic-Effort-Actions (BEA):**
   In this task, you will be asked to view visualization sequences generated by data captured from the trained CMA and dancer performing each of the 8 BEAs. You will be asked to match the visualization with the label of its corresponding Basic-Effort-Actions (BEAs), for each of System A, System B, and System C.

The evaluation will take approximately 35 - 40 minutes to complete. You can save your data at any time, and come back to the survey later. Your participation in this study is entirely voluntary. You can discontinue your participation at any time by clicking on the ‘exit and clear survey’ button on the bottom right of the screen and your data will be cleared. You can exit the survey by closing the current web browser and your data will be discarded.

**Study Details**

**Purpose of Research:** This study aims to:

1) Validate the consistency and accuracy of the Laban Movement Analysis Effort Framework to codify recognizable movement qualities, specifically the Basic Effort Actions (BEAs).

2) Validate the ability of trained CMA certified Laban Movement Analysts to identify the eight Basic-Effort-Actions (BEAs) in short movement sequences performed by a trained CMA and dancer.

3) Evaluate the communicative ability of three difference versions of the EMVIZ visualization system (System A, System B, and System C) in conveying the 8 Basic Effort Actions in a form of abstract expressive animations or visualizations. Each of the 3 versions of the visualization system use exactly the same input movement data captured from the trained CMA and dancer referred to above in (2).

Your responses to the questions will help us to validate the LMA system and the ability of CMA trained Laban Movement Analysts to recognize and evaluate Effort Qualities. Based on the knowledge of CMA trained experts to recognize the 8 BEAs, your observation and analysis of the different visualization systems will help us to compare and evaluate the communicative efficacy of three different versions of the EMVIZ visualization system. Additionally, your responses to the questions in this survey will help to construct a framework that describes a design process for articulating movement quality visualizations. This includes: an underlying model for capturing and mapping movement qualities to a visualization system, an evaluation methodology, and the ability to communicate information through a participant’s experience.

**What you will be asked to:**

1) watch a series of videos that depict movement qualities (BEAs) performed by a dancer and then match the video to one of the 8 Basic Effort Actions (BEAs).

2) watch a series of videos that depict visual representations of movement quality (BEAs) generated by EMVIZ visualization system based on the movement of the dancer and match the visualization to one of the 8 Basic Effort Actions (BEAs).

**Data Being Collected:**
Your responses from the online survey will be collected. All data collected will be assigned an anonymous participant code. All the information you supply will be confidential with respect to the SFU Director of Ethics Approval. The data will be stored securely and accessed only by researchers associated with this study.

**Questions about the Research:**
If you have questions about the research in general, please feel free to contact Pat Subyen either by telephone at 778-384-4935 or by email (psubyen@sfu.ca). This research project has been reviewed and approved by SFU’s Research Ethics Board and conforms to the standards of the Canadian Tri-Council Research Ethics guidelines. If you want to receive results and publications based upon this experiment, please feel free to contact Pat Subyen via telephone or email provided above.

**By Reading the following Consent Statement and Clicking NEXT you are agreeing to the following statements.**

I am being asked to participate in a research study on movement quality visualization evaluation. I acknowledge that I have read and understand the information provided above. I understand that all of the data I provide will be anonymously maintained, analyzed, presented and published. You may proceed by clicking "Next" button. By clicking "Next" button, you have read and understood the participant consent statement and willingly agree, free of coercion, undue influence and consent to participate in this research study. If you decide not to participate, you may close the current web browser.

There are 22 questions in this survey.

**Figure 5.3. Online survey – page one (survey details and online participant consent statement)**

*Note.* This study was approved by SFU Office of Research Ethics as a minimal risk study (see Appendix B, section 5).
Figure 5.4. Online survey – page two
Part 1 of the study was the LMA validation, which was divided into two tasks: the eight Basic-Efforts identification and the eight Basic-Effort-Actions within the Diagonal Scale identification. In these two tasks, the survey asked participants:

- There are eight movement sequences illustrated below, each performed by the same dancer (Fig. 5.6). Each movement sequence represents one of the eight Basic-Effort-Actions from Laban’s Action Drive. Please review the movement sequences, and then match each movement sequence (denoted as movement sequence 1-8) with its corresponding Basic-Effort-Actions (BEA) according to Laban Movement Analysis Efforts theory.

- Please identify the order (sequence) of the eight Basic-Effort-Actions (BEAs) in this movement sequence performed by a dancer (Fig. 5.6).

The first task measured the participant’s ability to identify movement sequences with its corresponding Basic-Effort-Action. The second task measured the participant’s ability to identify the order (sequence) of the eight Basic-Effort-Actions in the movement sequence. These two tasks helped validate the consistency and accuracy of the LMA Effort framework and the ability of trained CMA certified Laban Movement Analysts to identify the eight Basic-Effort-Actions in short movement sequences performed by a trained CMA dancer. For these tasks, the matrix question was designed to allow participants to match a series of possible answers on the y-axis to possible options along the x-axis (Fig. 5.5).

<table>
<thead>
<tr>
<th>answer1</th>
<th>answer2</th>
<th>answer3</th>
<th>answer4</th>
<th>answer5</th>
<th>answer6</th>
<th>answer7</th>
<th>answer8</th>
</tr>
</thead>
<tbody>
<tr>
<td>option1</td>
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<tr>
<td>option5</td>
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<tr>
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<tr>
<td>option7</td>
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</tbody>
</table>

Figure 5.5. Question and task design for Study Part 1 (LMA Validation)

To test the matrix question design’s usability, three participants with dance and LMA Effort theory experience were selected to participate in a pilot survey study. Figure 5.6 presents the first version of Part 1’s survey design.
After the test session, the participants provided feedback on the survey interface, as follows: (1) embedding eight videos in one page made the survey page load very slowly, (2) opening a new page for each video was better than playing each video on the same page, (3) limiting or not allowing participants to select the same answer twice on the matrix question helped to prevent error or incomplete data, and (4) organizing movement sequences on the Y axis and Basic-Effort-Actions in X axis would be easier to understand because we read from left to right rather than top to bottom. These comments were used to improve and design the final version of the survey. Figure 5.7 presents Study Part 1 (LMA validation).
Figure 5.7. Study Part 1 (LMA Validation)

Note. See Study Part 1 materials in Appendix B, section 2.
Parts 2, 3, and 4 of the study involved the evaluation of three different versions of the EMVIZ visualization system. In these three parts, the three EMVIZ systems were called System A (Motion-Agent), System B (Sketch), and System C (L). Each part was divided into three tasks: eight Basic-Effort-Actions visualization recognition, Basic-Effort-Actions parameter values identification, and feedback on the effectiveness of system ability to communicate the eight Basic-Effort-Actions. In these three tasks, the survey asked participants:

- Please review the movement sequence videos and then watch the System (A or B or C) visualization videos (Figs. 5.8, 5.9, and 5.10). The visualization videos were generated from the movements of the eight Basic-Effort-Actions shown in the movement sequences. Each visualization sequence can be matched to one of the eight Basic-Effort-Action movement sequences. Based on your viewing, please answer the questions in following sections:

- Please match each visualization video with movement sequence video.

- Please identify which Effort parameter values you have recognized in each of the visualization videos.

- You have just viewed visual representations of the eight Basic-Effort-Actions generated by EMVIZ (System A or B or C). Please write down your responses regarding the effectiveness of System (A’s or B’s or C’s) ability to communicate the eight Basic-Effort-Actions through the following: visual appearance, colour, dynamics, and clarity of communication.

In Task 1, the communicative ability of the eight Basic-Effort-Actions visualization was measured using the matrix question design to obtain participant responses. This task measured whether visualizations were able to communicate the eight Basic-Effort-Actions or eight movement qualities. Task 2 asked participants for more analyses of each visualization in order to determine whether participants were able to identify Effort parameters presented in the visualization. This task helped to describe what Effort parameters were presented and recognized or not by the participants. Task 3 was an open question that allowed participants to provide feedback about the EMVIZ (System A or B or C). This task aimed to gain qualitative information to support quantitative data in Tasks 1 and 2. Figures 5.8, 5.9, and 5.10 present Study Part 2 (System A), Part 3 (System B), and Part 4 (System C), respectively.
Figure 5.8. Study Part 2: EMVIZ (System A) evaluation

Note. See Study Part 2 materials in Appendix B, section 2.
Figure 5.9. Study Part 3: EMVIZ (System B) evaluation

Note. See Study Part 3 materials in Appendix B, section 2.
Figure 5.10. Study Part 4: EMVIZ (System C) evaluation

Note. See Study Part 4 materials in Appendix B, section 2.
Finally, Part 5 (Fig. 5.11) presented a comments question that allowed participants to provide overall feedback on the EMVIZ Systems (A or B or C).

![Image of survey interface](image)

Figure 5.11. Study Part 5: Feedback on EMVIZ (System A or B or C)

### 5.4. Study Procedure

Certified Movement Analysts (CMAs) were recruited through invitation email via Dr. Thecla Schiphorst and Karen Bradley, Executive Director and Director of Research of Laban/Bartenieff Institute of Movement Studies in New York City. Thirty CMAs responded and expressed interest in participating in the survey, and they were sent a formal invitation email with study details (Fig. 5.12). Finally, 15 CMAs participated and 12 CMAs completed the survey.
From: Pat Subyen <pats@sfu.ca>
Subject: possibilities of CMAs for Pat Subyen's survey
To: 

Dear CMA,

We are seeking Certified (Laban) Movement Analysts (CMAs) to participate in a study that explores how the Basic Effort Actions (BEAs) of Action Drive can be communicated through different digital visualization systems. We use a system called 'EMVIZ' to explore the Evaluation of a set of three different Movement Quality Visualization Systems. You are invited to participate in a research survey conducted by Pat Subyen, a Ph.D student at Simon Fraser University, under the guidance of faculty supervisors, Dr. Thecla Schiphorst and Dr. Philippe Pasquier.

This study aims to:

1. Validate the consistency and accuracy of the Laban Movement Analysis Effort Framework to codify recognizable movement qualities, specifically the Basic Effort Actions (BEAs).
2. Validate the ability of trained CMA certified Laban Movement Analysts to identify the eight Basic-Effort-Actions (BEAs) in short movement sequences performed by a trained CMA and dancer.
3. Evaluate the communicative ability of three difference versions of the EMVIZ visualization system (System A, System B, and System C) in conveying the 8 Basic Effort Actions in a form of abstract expressive animations or visualizations. Each of the 3 versions of the visualization system use exactly the same input movement data captured from the trained CMA and dancer referred to above in (2).

As a participant of this study you will help to validate LMA knowledge illustrated through observation and analysis skills. In the survey, you will be asked to complete two tasks described below:

1. Identify the LMA Basic-Effort-Actions:
   In this first task, you will be asked to view 8 short video recordings of a trained CMA and dancer performing one of the Basic-Effort-Actions (BEA) and after each of the 8 shorts clips, associate the video with the label (or name) of that Basic-Effort-Action (BEA). You will be asked to view and identify each of the eight Basic-Effort-Actions described by Rudolf Laban.

2. Evaluate a set of 8 visualizations (for each of System A, System B and System C) that represent each of the Basic-Effort-Actions (BEA):
   In this task, you will be asked to view visualization sequences generated by data captured from the trained CMA and dancer performing each of the 8 BEAs. You will be asked to match the visualization with the label of its corresponding Basic-Effort-Actions (BEAs), for each of System A, System B, and System C.

The evaluation will take approximately 35 - 40 minutes to complete.

Your responses to the questions will help us to validate the LMA system and the ability of CMA trained Laban Movement Analysts to recognize and evaluate Effort Qualities. Based on the knowledge of CMA trained experts to recognize the 8 BEAs, your observation and analysis of the different visualization systems will help us to compare and evaluate the communicative efficacy of three different versions of the EMVIZ visualization system. Additionally, your responses to the questions in this survey will help to construct a framework that describes a design process for articulating movement quality visualizations. This includes: an underlying model for capturing and mapping movement qualities to a visualization system, an evaluation methodology, and the ability to communicate information through a participant’s experience.

Compensation is $20 Amazon gift card.

If you are interested in participating in this research, please visit http://movement.iat.sfu.ca/survey/

Upon completion of the survey, you will be sent the Amazon Gift Card.

Sincerely,
Pat Subyen
(for Thecla Schiphorst & Philippe Pasquier)

Figure 5.12. Formal invitation email with study details

To participate in the survey, participants clicked on the web URL provided in the formal invitation email, which led to the first page of the survey (Fig. 5.3). All participants were asked to review a consent form before deciding to participate in the research survey. Participants were informed that all survey responses would be recorded and anonymously maintained, analyzed, presented, and published. All information is
confidential with respect to law and the survey responses would be saved on a secure School of Interactive Arts and Technology, Simon Fraser University web server. After clicking the “Next” button, participants read and understood the consent statement and willingly consented, free of coercion or undue influence, to participate in this research study. Participants were also informed that they could close the current webpage and quit the survey, if they decided not to participate.

The survey had five parts and each participant was asked to complete survey tasks described as follows:

- Registration: Fill in demographic information (Fig. 5.4).

- Part 1: View eight short video recordings of a trained CMA dancer performing a Basic-Effort-Action and after each video clip, associate the video with the label (or name) of that Basic-Effort-Actions (Fig. 5.7).

- Part 2-4: View visualization sequences generated by data captured from the trained CMA dancer performing each of eight Basic-Effort-Actions. Participants were asked to match the visualization with the label of its corresponding Basic-Effort-Action and provide written feedback for EMVIZ System A, System B, and System C (Figs. 5.8, 5.9, 5.10).

- Part 5: Provide overall feedback about EMVIZ (System A, System B, and System C) and email to receive a $20 Amazon Gift Card.
5.5. Data Analysis

This section describes the analytical procedures and statistical methods used to analyze data collected from the study. The study had two main sections: LMA validation (section 1) and EMVIZ systems evaluation (section 2-4). For LMA validation, the study first recorded participant responses for correct matching between movement sequence and the Basic-Effort-Action’s label or name. The study then recorded participant responses for correct identification of the order (sequence) of the Basic-Effort-Actions in a continuous movement sequence performed by a dancer. To evaluate EMVIZ systems, the study recorded participant responses for correct matching between Basic-Effort-Actions movement sequences and Basic-Effort-Actions visualizations among three EMVIZ systems. The study then recorded participant responses for correct identification of Effort parameter values of each Basic-Effort-Actions visualization. Finally, feedback was recorded regarding the communicative ability (i.e., visual appearance, colour, dynamics, and clarity of communication) of each EMVIZ system.

To prepare data for statistical analysis, I first cleaned up the original output data from the online survey system (see original output data in Appendix B, section 3). This was done to make sure that there were no errors in data collection such as participants accidentally recording incorrect information. The cleaned-up data for all participants was reformatted into a new Microsoft Excel file, while each participant’s data was reformatted into a Microsoft Word file (see survey summary in Appendix B, section 4). After data checks and corrections, the next step was choosing the right statistical methods and models for data analysis.

In the first section of the study (LMA validation section), descriptive statistics was used as a method to analyze and describe data. This is because, during data checking, I found that all participants correctly performed 100% for task 1 and 2 (see Chapter 6, section 6.2). Thus, there was no need to perform inferential statistics on this part of the study. For section 2-4 (EMVIZ evaluation), three research questions and three hypotheses were presented in the beginning of this chapter. Table 5.2 summarizes research questions, hypotheses, and analytical methods.
Table 5.2. Research questions, hypotheses, and analytical methods

<table>
<thead>
<tr>
<th>Research Question</th>
<th>Hypothesis</th>
<th>Analysis Method</th>
</tr>
</thead>
</table>
| RQ1. Is there a difference among systems in correct matching between Basic-Effort-Actions movement sequences and Basic-Effort-Actions visualizations? If there is a significant difference, which visualization among systems is significantly different and performs better than the others? | $H_1$: There is a difference in percentage of correct matching between Basic-Effort-Actions movement sequences and Basic-Effort-Actions visualizations among systems for each Basic-Effort-Action visualization with respect to their p-values (probability). | 1. Descriptive Statistics  
2. Cochran-Mantel-Haenszel Test  
3. Cochran-Mantel-Haenszel Pairwise Comparisons |
| RQ2. Is there a difference among systems in correct identification of Effort parameter values (Space, Weight, Time) for each Basic-Effort-Action visualization? If there is a significant difference, which Effort parameter (Space, Weight, Time) is significantly different and performs better than others? | $H_1$: There is a difference in percentage of correct Effort parameter values identification among systems with respect to their p-values (probability). | 1. Descriptive Statistics  
2. Cochran-Mantel-Haenszel Test  
3. Cochran-Mantel-Haenszel Pairwise Comparisons |
| RQ3. Is there a difference among systems in mean number for correct matching of Basic-Effort-Actions visualizations and correct Effort parameter values identification? | $H_1$: There is a difference in mean number for (1) correct matching between Basic-Effort-Actions movement sequences and Basic-Effort-Actions visualizations and (2) Effort parameter values identification, with respect to their p-values (probability). | 1. ANOVA (F-Test)  
2. T-Test Pairwise Comparisons |

In order to answer research question 1-3 (RQ1-3) and test the three hypotheses ($H_1$, $H_2$, $H_3$), descriptive and inferential statistics were used to present and compare the communicative ability of three EMVIZ systems. Task 1 and 2 of the study part 2-4 were analyzed using different methods and statistical models.

To successfully analyze collected data from the EMVIZ systems evaluation and answer RQ1-3, I consulted with Simon Fraser University’s statistical consulting service\(^4\) led by Tom Loughin, a Professor in the Department of Statistics and Actuarial Science, and Marie Loughin, an experienced statistician. After discussing statistical models for data analysis with them, the data analysis plan was separated into two parts. First, to

\(^4\) SFU Statistical Consulting Service is a unit that provides expert statistical advice and statistical analysis services, see: Http://people.stat.sfu.ca/~tloughin/SFU_Surrey_Stat_Con_Service.htm
answer RQ1-2, a separate analysis was performed for each Basic-Effort-Action visualization in each EMVIZ system using the Cochran-Mantel-Haenszel \(^5\) (CMH) statistical test, which is a test for detecting the association between two categorical variables observed in K strata (statistics.com 2004; sas.com 2013). Second, to answer RQ3, analysis of variance (ANOVA) was performed to analyze the differences between EMVIZ system means and their variation among systems.

To perform two parts of data analysis, I defined the study's response variables\(^6\) as “matching” (1=correct and 0=incorrect) and “the number of visualization correctly matched.” Matching is the categorical variable and it was used in analytical procedures for answering RQ1-2. The number of visualizations correctly matched is a count variable, which was treated as a continuous numerical variable used for answering RQ3. The experimental unit is visualization within the system or “matching opportunity,” defined as the opportunity to choose which movement sequence matches which particular visualization. System (i.e., three EMVIZ systems) is the treatment or explanatory variable.\(^7\) To control the tendency towards similarity of responses from participants and improve the power to detect differences among compared systems, “participant” was stratified and used as a stratification variable\(^8\) or a block variable\(^9\). Participant is included as a stratification variable in the Cochran-Mantel-Haenszel test and as a block variable in an analysis of variance (ANOVA). Table 5.3 summarizes variable types for data analysis of the present study.

---


\(^6\) Response variable is the outcome of a study or a variable for predicting or forecasting. It is often called a dependent variable (Reinard 2006, p.18), see: Reinard, J. C. (2006). Communication Research Statistics. SAGE.

\(^7\) Explanatory variable explains the response variable. It is often called independent variables, which are “variables that can be used to predict or explain the values of another variable (Reinard 2006, p.18; Preston 2013), see: Reinard, J. C. (2006). Communication Research Statistics. SAGE.

\(^8\) Stratification variable is a variable or variables by which a study population is divided up into strata (or groups) in order to select a stratified sample (Geo 2013), see: http://www-personal.ksu.edu/~goe/lec05bsl/sld019.htm.

\(^9\) Blocking is a technique that is used for arranging experimental units in groups or blocks that are similar to one another. This is to reduce source of variability and improve comparisons of treatments by randomly allocating the treatments within each block (Easton & McColl 1997), see: http://www.stats.gla.ac.uk/steps/glossary/anova.html#block
Table 5.3. Summary of variable type for data analysis

<table>
<thead>
<tr>
<th>Category</th>
<th>Variable Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>System (A, B, C)</td>
<td>Explanatory variable (independent or predictor variable)</td>
</tr>
<tr>
<td>Correct matching between Basic-Effort-Actions movement sequences and Basic-Effort-Actions visualizations (1=correct, 0=incorrect)</td>
<td>Response Variable (dependent variable)</td>
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<tr>
<td></td>
<td>1. Matching: category variable (CMH)</td>
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<tr>
<td></td>
<td>2. Count: a continuous numerical variable (ANOVA)</td>
</tr>
<tr>
<td>Participant</td>
<td>Stratification variable for CMH test</td>
</tr>
<tr>
<td></td>
<td>Block variable for ANOVA test</td>
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</tbody>
</table>

Note: In data analysis, EMVIZ (Motion-Agent), EMVIZ (Sketch), and EMVIZ (L) was denoted as system A, B, and C respectively. See formatted data for statistical analysis (Data-listing-analysis.rtf) in Appendix B, section 3.

In order to use the CMH test to answer **RQ 1-2**, first, the participant was stratified as described in Table 5.3. This would test for association between matching Basic-Effort-Actions movement sequences with Basic-Effort-Actions visualizations and systems (**RQ1**) and association between identifying Effort parameters values and systems (**RQ2**). This process would reveal the frequencies for correctly matched and incorrectly matched Basic-Effort-Actions movement sequences and Basic-Effort-Actions visualizations as well as correctly and incorrectly identified Effort parameters values among three EMVIZ systems. If there was a significant difference among systems, a pairwise comparison between systems (i.e., EMVIZ (Motion-Agent) vs. EMVIZ (Sketch), EMVIZ (Motion-Agent) vs. EMVIZ (L), EMVIZ (Sketch) vs. EMVIZ (L)) could be performed. This would reveal which particular Basic-Effort-Action visualization and Effort parameter values on which system differed from the other two systems or that all three EMVIZ systems differed from each other.

Secondly, for each system, a responsive variable could be created according to the number of correctly matching Basic-Effort-Actions movement sequences to visualizations and the number of correct identifications of Effort parameters values. Thus, the number of correct matches and correct identifications for each system was calculated and used as the response variable (i.e., a continuous numerical variable).
These variables were analyzed using analysis of variance (ANOVA\textsuperscript{10}), with system as the explanatory variable and participant as a block variable, as described in Table 5.3. If there was a significant difference between systems in the number of correct matches or identifications, then the pairwise comparisons of mean number of correct matches and identifications between systems could be performed. This provided the estimated mean number of correct matches and correct identifications (least squares means). This process answered RQ3.

In the next chapter, I present the results of the study and answer all research questions defined in this chapter.

\textsuperscript{10} Anova is a statistical method which helps in making inferences whether three or more samples might come from populations having the same mean; specifically, whether the differences among the samples might be caused by chance variation. ANOVA tests are also called “F-test” (Statistics.com 2014), see: http://statistics.com/glossary&term_id=609
Chapter 6.

Usability Testing Results

6.1. Participant Demographics

Figure 6.1 presents demographics information for the 12 participants.

Note. In this context, expert means the participant applies movement expertise experience and theory to their professional practice, while professional means that the participant engages in dance movement activity as their main occupation.
In this study, 12 CMAs completed the survey. All of them were female. Of the 12 participants, two were between 35-44 years old, four were 45-54, five were 55-64 and one was 65 and above. Ten have Masters degrees and two have PhD and Bachelor degrees. Eight participants’ occupation involved movement and education fields (i.e., college teacher or university professor), two were retired teachers, and two were a dance movement therapist and the owner of a private dance company, respectively. All participants received a certified movement analyst certificate from the LABAN/BARTENIEFF Institute of Movement Studies (LIMS). Five participants completed the training from LIMS New York, while the others completed the training from the LIMS joint program at other institutions (e.g., University of Maryland, Lesley University, and Université du Québec à Montréal). Eight participants completed training between 1980-1999, while four completed training between 2000-2013. Three have other movement certificates, such as the Alexander technique, Franklin method, and Somatics certificate. Nine participants considered themselves experts and professionals, and three considered themselves experts. Seven participants applied LMA knowledge in their daily activities, four often or regularly applied LMA in daily activities, and one did not often use LMA in daily activities. Dance and movement teaching were the most common field of study that all participants applied LMA to.

6.2. LMA Validation

All participants correctly matched 100% of the eight Basic-Effort-Action labels (or names) with movement sequences and correctly identified the order of eight Basic-Effort-Action labels (or names) in a continuous movement sequence (see Appendix C, section 2.1 - 2.2). The results suggest that all participants (CMAs) have consistent and accurate observational ability to identify Basic-Effort-Actions in postural effortful actions in movement sequence. Results also indicate that the LMA Effort framework is a valid framework for classifying recognizable the eight Basic-Effort-Actions or movement qualities¹ according to inter-rater reliability among CMAs. If the framework was not

¹ This assumption is not included the eight Basic-Effort-Actions in gestural actions of one body part or free movement. See more information about the eight Basic-Effort-Actions in the glossary section.
reliable or precise for describing movement qualities, then the participants would not be able to apply and accurately identify eight qualities in movement sequences and visualization. Thus, this study could rely on participants’ observational skills in classifying recognizable Basic-Effort-Actions visualizations generated by the three EMVIZ systems.

6.3. EMVIZ Evaluation

The EMVIZ evaluation results were divided into three main parts: Basic-Effort-Actions visualization recognition, Effort parameter values identification, and feedback on systems A, B, and C. Part 1 and 2 present descriptive statistic results and address the research questions. Part 3 describes and summarizes feedback for each EMVIZ system.

6.3.1. Basic-Effort-Actions Visualization Identification

Figure 6.2 measures and compares the average percentage of correct matching between Basic-Effort-Actions movement sequences and Basic-Effort-Actions visualizations for systems A to C in order to gauge the precision of each EMVIZ system. Correct matching means that each Basic-Effort-Action visualization is associated with each Basic-Effort-Action movement sequence that it was intended to represent. The standard grade system was used to describe system performance or precision (i.e., 100%-85% = excellent performance, 84%-70% = good performance, 69%-60% = satisfactory performance, 59%-50% = marginal performance, and 0%-49% = failed or unsatisfactory performance). The average percentage of correctly matched movement with visualization for each system was calculated based on the total number of correct matches for each visualization divided by the number of visualizations (eight).
From the 12 participants’ responses, the percentage of correct matches ranged from 0% to 91.7%. For system A, the average percentage of correct matches is 47.9%. The results suggest excellent communicative ability for Glide (91.7%) and good performance for Wring (83.3%), Press (75%), and Float (83%) visualizations. However, system A fails to communicate Punch (25%), Dab (16.7%), Slash (8.3%), and Flick (0%) visualizations.

For system B, the average percentage of correct matches is 55.2%. The results suggest good communicative ability for Punch (83.3%) and Float (75%) visualizations, satisfactory performance for Slash (66.7%) and Glide (66.7%) visualizations, marginal performance for Dab (50%) and Flick (50%) visualizations, and failed performance for Wring (16.7%) and Press (33.3%) visualizations.

For system C, the average percentage of correct matching is 37.5%. The results suggest satisfactory communicative ability for Punch visualization (66.7%) and failed performance for Wring (41.7%), Press (41.7%), Float (41.7%), Dab (25%), Slash (33.3%), Flick (25%), and Glide visualizations (25%).
Table 6.1 presents the correlation matrix of matching frequencies between Basic-Effort-Action movement sequences and Basic-Effort-Action visualizations among systems. Correct matches are presented in diagonal scale, and systems A, B, and C are colour coded as blue, cyan, and orange, respectively. The table also shows the number of participants that correctly and/or incorrectly matched movement with visualization for each Basic-Effort-Action. For instance, in system A (coded blue), three participants (25%) correctly matched the Punch movement sequence to Punch visualization, while seven participants (58.3%) incorrectly matched Punch movement with Slash, one participant (8.3%) incorrectly matched Punch with Dab, and one participant (8.3%) incorrectly matched Punch with Glide.

### Table 6.1. Correlation matrix of matching frequencies among systems

<table>
<thead>
<tr>
<th>Movement</th>
<th>Punch</th>
<th>Dab</th>
<th>Slash</th>
<th>Flick</th>
<th>Glide</th>
<th>Wring</th>
<th>Press</th>
<th>Float</th>
</tr>
</thead>
<tbody>
<tr>
<td>Punch</td>
<td>3,10,8</td>
<td>1,1,0</td>
<td>7,1,2</td>
<td>0,0,0</td>
<td>1,0,0</td>
<td>0,0,0</td>
<td>0,0,1</td>
<td>0,0,1</td>
</tr>
<tr>
<td>Dab</td>
<td>7,0,1</td>
<td>2,6,3</td>
<td>1,1,4</td>
<td>2,3,4</td>
<td>0,1,0</td>
<td>0,1,0</td>
<td>0,0,0</td>
<td>0,0,0</td>
</tr>
<tr>
<td>Slash</td>
<td>0,1,2</td>
<td>2,1,0</td>
<td>1,8,4</td>
<td>9,1,4</td>
<td>0,0,0</td>
<td>0,1,0</td>
<td>0,0,1</td>
<td>0,0,1</td>
</tr>
<tr>
<td>Flick</td>
<td>2,1,0</td>
<td>7,2,7</td>
<td>2,1,0</td>
<td>0,6,3</td>
<td>0,1,0</td>
<td>0,0,0</td>
<td>0,1,0</td>
<td>1,1,1</td>
</tr>
<tr>
<td>Glide</td>
<td>0,0,0</td>
<td>0,0,1</td>
<td>0,0,0</td>
<td>0,0,0</td>
<td>11,8,3</td>
<td>0,1,3</td>
<td>1,1,1</td>
<td>0,2,4</td>
</tr>
<tr>
<td>Wring</td>
<td>0,0,3</td>
<td>0,0,1</td>
<td>1,1,0</td>
<td>0,1,1</td>
<td>0,3,2</td>
<td>10,2,5</td>
<td>1,5,0</td>
<td>0,0,0</td>
</tr>
<tr>
<td>Press</td>
<td>0,0,0</td>
<td>0,1,0</td>
<td>0,0,0</td>
<td>1,0,0</td>
<td>0,0,3</td>
<td>1,6,4</td>
<td>9,4,5</td>
<td>1,1,0</td>
</tr>
<tr>
<td>Float</td>
<td>0,0,1</td>
<td>0,1,0</td>
<td>0,0,2</td>
<td>0,1,0</td>
<td>0,0,3</td>
<td>1,0,0</td>
<td>1,1,1</td>
<td>10,9,5</td>
</tr>
</tbody>
</table>

Note. System: A = blue, B = cyan, C = orange. Frequencies: 1 = 8.3%, 2 = 16.7%, 3 = 25%, 4 = 33.3%, 5 = 41.7%, 6 = 50%, 7 = 58.3%, 8 = 66.7%, 9 = 75%, 10 = 83.3%, 11 = 91.7%, and 12 = 100%. See a separate correlation matrix of matching frequencies for each system in Appendix C, section 2.3.1 - 2.3.3.

To summarize, the descriptive statistical results indicate that system A fails to communicate movement quality in terms of average percentage (47.9%) and has poor communicative ability (below 25%) for Sudden movement (i.e., Punch, Dab, Slash, and Flick visualizations). However, it has good communicative ability (above 75%) for Sustained movement (i.e., Glide, Wring, Press, and Float visualizations). System B has marginal communicative ability for communicating movement quality in terms of average percentage (55.2%). It has satisfactory communicative ability (above 66.7%) for Punch, Slash, Glide, and Float visualizations and unsatisfactory ability (50% and below) for Dab, Flick, Wring, and Press visualizations. System C fails to communicate movement quality in terms of average percentage (37.5%) and it has a very poor communicative
ability for the majority of visualizations (below 41.7%), except for Punch visualization. According to the average percentages of system precision, system B has the best communicative ability, followed by systems A and C.

To answer RQ1, “which Basic-Effort-Actions visualization among systems is significantly different and performs better than others?”, the CMH test was performed to determine if there was a significant difference among systems in correct matches between Basic-Effort-Action movement sequences and Basic-Effort-Action visualizations per Basic-Effort-Action visualization. Table 6.2 presents CMH test results.

Table 6.2. Cochran-Mantel-Haenszel test results for correct matching between Basic-Effort-Action movement sequences and Basic-Effort-Action visualizations

<table>
<thead>
<tr>
<th>BEA Visualization</th>
<th>DF²</th>
<th>Value</th>
<th>Prob</th>
</tr>
</thead>
<tbody>
<tr>
<td>Punch</td>
<td>2</td>
<td>8.6667</td>
<td>0.0131</td>
</tr>
<tr>
<td>Dab</td>
<td>2</td>
<td>2.8889</td>
<td>0.2359</td>
</tr>
<tr>
<td>Slash</td>
<td>2</td>
<td>8.2222</td>
<td>0.0164</td>
</tr>
<tr>
<td>Flick</td>
<td>2</td>
<td>7.7143</td>
<td>0.0211</td>
</tr>
<tr>
<td>Glide</td>
<td>2</td>
<td>9.8000</td>
<td>0.0074</td>
</tr>
<tr>
<td>Wring</td>
<td>2</td>
<td>9.8000</td>
<td>0.0074</td>
</tr>
<tr>
<td>Press</td>
<td>2</td>
<td>4.2000</td>
<td>0.1225</td>
</tr>
<tr>
<td>Float</td>
<td>2</td>
<td>4.6667</td>
<td>0.0970</td>
</tr>
</tbody>
</table>

Note. The significant results are highlighted in grey. See the result of data analysis from SAS software in Appendix C, section 1 (Match_move rq1 CMH results.rft).

CMH test results confirmed that there is a significant difference with respect to p-value < 0.05 for Punch (p = 0.0131), Slash (p = 0.0164), Flick (p = 0.0211), Glide (p = 0.0074), and Wring (p= 0.0074) visualizations. Thus, this result rejects a null hypothesis. As shown in Figure 6.2, system B’s Punch, Slash, and Flick visualizations had the best communicative ability compared to the other two EMVIZ systems (by 83.3%, 66.7%, and 50%, respectively). However, system A had the best communicative ability for Glide visualization (91.67%) and Wring visualization (83.3%). In contrast, system C did not have the best communicative ability for any Basic-Effort-Action visualization.

² Degrees of Freedom (DF), a set of data points in a given situation, is the minimal number of values which should be specified to determine all the data points. See: http://www.statistics.com/glossary&term_id=225
To answer the second part of RQ1, CMH pairwise comparisons among systems were performed for the Basic-Effort-Actions visualizations that showed significant differences in p-value < 0.05 (i.e., Punch, Slash, Flick, Glide, and Wring visualizations), in order to compare systems A to B, A to C, and C to B in terms of percentage of correct matches. This was done to identify the source of the significance and detect whether two systems were different regardless of which one performed better. Table 6.3 presents the CMH pairwise comparisons results.

Table 6.3. Cochran-Mantel-Haenszel pairwise comparisons results

<table>
<thead>
<tr>
<th>Visualization</th>
<th>Comparison Between Systems</th>
<th>DF</th>
<th>Value</th>
<th>Prob</th>
<th>Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Punch</td>
<td>A versus B</td>
<td>1</td>
<td>7.0000</td>
<td>0.0082</td>
<td>B (83.3%) &gt; A (25%)</td>
</tr>
<tr>
<td></td>
<td>A versus C</td>
<td>1</td>
<td>3.5714</td>
<td>0.0588</td>
<td>A = C</td>
</tr>
<tr>
<td></td>
<td>B versus C</td>
<td>1</td>
<td>1.0000</td>
<td>0.3173</td>
<td>B = C</td>
</tr>
<tr>
<td>Slash</td>
<td>A versus B</td>
<td>1</td>
<td>5.4444</td>
<td>0.0196</td>
<td>B (66.7%) &gt; A (8.3%)</td>
</tr>
<tr>
<td></td>
<td>A versus C</td>
<td>1</td>
<td>3.0000</td>
<td>0.0833</td>
<td>A = C</td>
</tr>
<tr>
<td></td>
<td>B versus C</td>
<td>1</td>
<td>2.6667</td>
<td>0.1025</td>
<td>B = C</td>
</tr>
<tr>
<td>Flick</td>
<td>A versus B</td>
<td>1</td>
<td>6.0000</td>
<td>0.0143</td>
<td>B (50%) &gt; A (0%)</td>
</tr>
<tr>
<td></td>
<td>A versus C</td>
<td>1</td>
<td>3.0000</td>
<td>0.0833</td>
<td>A = C</td>
</tr>
<tr>
<td></td>
<td>B versus C</td>
<td>1</td>
<td>1.8000</td>
<td>0.1797</td>
<td>B = C</td>
</tr>
<tr>
<td>Glide</td>
<td>A versus B</td>
<td>1</td>
<td>1.8000</td>
<td>0.1797</td>
<td>A = B</td>
</tr>
<tr>
<td></td>
<td>A versus C</td>
<td>1</td>
<td>6.4000</td>
<td>0.0114</td>
<td>A (91.7%) &gt; C (25%)</td>
</tr>
<tr>
<td></td>
<td>B versus C</td>
<td>1</td>
<td>5.0000</td>
<td>0.0253</td>
<td>B (66.7%) &gt; C (25%)</td>
</tr>
<tr>
<td>Wring</td>
<td>A versus B</td>
<td>1</td>
<td>8.0000</td>
<td>0.0047</td>
<td>A (83%) &gt; B (16.7%)</td>
</tr>
<tr>
<td></td>
<td>A versus C</td>
<td>1</td>
<td>3.5714</td>
<td>0.0588</td>
<td>A = C</td>
</tr>
<tr>
<td></td>
<td>B versus C</td>
<td>1</td>
<td>1.8000</td>
<td>0.1797</td>
<td>B = C</td>
</tr>
</tbody>
</table>

Note. The significant results are highlighted in grey. A = EMVIZ (Motion-Agent), B = EMVIZ (Sketch), and C = EMVIZ (L). Greater-than sign (>) means “performs greater than.” Equals sign (=) means “no difference.” Percentage (%) refers to system’s precision presented in Figure 6.2. See the result of data analysis from SAS software in Appendix C, section 1 (CMH-pairwise-match_move.rtf). See a descriptive explanation for CMH pairwise comparisons test in Appendix C, section 3.1.

To summarize, the eight Basic-Effort-Actions visualizations generated by three EMVIZ systems were not equally able to communicate the movement quality they were intended to convey because there is a significant difference among systems in correctly matched Basic-Effort-Actions movement sequences with Basic-Effort-Actions visualizations for Punch, Slash, Flick, Glide, and Wring. For Punch, Slash, and Flick visualizations, system B is significantly different and performs better than system A. For Glide visualization, systems A and B are significantly different and perform better than system C. For Wring visualization, system A is significantly different and performs better.
than system B.

6.3.2. Effort Parameter Values Identification

Figure 6.3 (below) presents the correct identification (%) of Effort parameter values (Space, Time, Weight) for each Basic-Effort-Action visualization among systems. Here, correct identification means that each Effort parameter value is correctly identified according to LMA Effort theory. This measures the communicative ability of Effort parameter values for each Basic-Effort-Action visualization among systems according to the percentage of correct identification. It also helps identify which Effort parameter values is misinterpreted for each Basic-Effort-Action visualization among systems.

Figure 6.3. Effort parameter values precision among systems
Note. The six Effort parameter values (i.e., Direct, Indirect, Strong, Light, Sudden, Sustained) are colour coded as blue, magenta, brown, purple, light blue, and light brown, respectively (see a separate bar chart and a descriptive explanation for each system in Appendix C, section 2.3.4 – 2.3.6).
Figure 6.4 presents the average percentages\(^3\) of correct identification of all three Effort parameter values for each Basic-Effort-Action visualization among systems.

![Bar chart showing average percentages of correct identification of Effort parameter values for each Basic-Effort-Action visualization among systems.]

**Figure 6.4.** Average percentages of correct identification of Effort parameter values (Space, Time, Weight) for each Basic-Effort-Action visualization among systems

For system A, the results suggest marginal communicative ability of Effort parameter values for Punch, Dab, Slash, Flick, and Press visualizations. However, Glide, Wring, and Float visualizations were good at communicating Effort parameter values. For system B, the results suggest marginal communicative ability of Effort parameter values for Punch, Dab, and Flick visualizations, satisfactory performance for Slash and Glide, good performance for Float, and failed performance for Wring and Press. For system C, the results suggest satisfactory communicative ability for Slash visualization, marginal performance for Punch and Flick visualizations, and failure for the rest of the visualizations.

Table 6.4 presents the correlation matrix of Effort parameter values identification frequencies for each Basic-Effort-Action visualization among systems. In each row, correctly identified Effort parameter values among systems are presented in a diagonal

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\(^3\) The average percentage of correctly identified Effort parameter values for each visualization was calculated based on the total number of correctly identified Effort parameter values divided by 3 (i.e., the number of parameter values of each visualization).
scale as black cells. Each number in non-black cells represent incorrectly identified Effort parameter values for systems A, B, and C. The numbers are colour coded as blue, purple, and orange for systems A, B, and C, respectively. For instance, for system A’s Dab visualization, six participants (50%) correctly identified Direct (Space), three participants (25%) incorrectly identified Direct as Indirect, and three participants (25%) incorrectly chose either Direct or Indirect. Two participants (16.7%) correctly identified Light (Weight), five participants (41.7%) incorrectly identified Light with Strong, and five participants (41.7%) incorrectly chose neither Strong or Light. Twelve participants (100%) correctly identified Sudden Time.

Table 6.4. Correlation matrix of Effort parameter values identification frequencies for each Basic-Effort-Action visualization among systems

<table>
<thead>
<tr>
<th>Visualization / Effort Parameter Values</th>
<th>Target Effort Parameter Values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SPACE</td>
</tr>
<tr>
<td></td>
<td>D</td>
</tr>
<tr>
<td>Punch D S SUD</td>
<td>0,4,4</td>
</tr>
<tr>
<td>Dab D L SUD</td>
<td>6,2,1</td>
</tr>
<tr>
<td>Dab D S SUD</td>
<td>2,0,9</td>
</tr>
<tr>
<td>Dab D S SUD</td>
<td>4,3,1</td>
</tr>
<tr>
<td>Glide D L SUS</td>
<td>6,6,0</td>
</tr>
<tr>
<td>Wring D S SUS</td>
<td>4,7,2</td>
</tr>
<tr>
<td>Press D S SUS</td>
<td>6,3,1</td>
</tr>
<tr>
<td>Float D L SUS</td>
<td>3,1,1</td>
</tr>
</tbody>
</table>

Note. D = Direct, ID = Indirect, S = Strong, L = Light, SUD = Sudden, SUS = Sustained, and N = Neither. Frequencies: 1 = 8.3%, 2 = 16.7%, 3 = 25%, 4 = 33.3%, 5 = 41.7%, 6 = 50%, 7 = 58.3%, 8 = 66.7%, 9 = 75%, 10 = 83.3%, 11 = 91.7%, and 12 = 100%. See a separate correlation matrix diagram for each
system in Appendix C (section 2.3.7 – 2.3.9).

Figure 6.5 (below) summarizes the average percentage of correctly identified Effort parameter values among systems, calculated based on the total of correctly identified values for each Basic-Effort-Action visualization divided by the number of visualizations (four). For instance, the average of Sudden Time Effort parameter for system A is the total of correct identifications of Punch (100%), Dab (100%), Slash (91.7%), and Flick (75%) visualizations divided by 4.

![Figure 6.5. The average percentage of correctly identified Effort parameter values among systems](image)

*Note.* See a descriptive explanation in Appendix C (2.3.10).

To answer **RQ2**—“Which Effort parameter among systems is significantly different and performs better than others?”—a CMH test was performed to determine if there was a significant difference among systems in correct identifications of the three Effort parameter values (Space, Weight, Time) for each Basic-Effort-Action visualization. Table 6.5 (below) presents CMH test results.
The CMH test indicated that there is a significant difference among systems in correctly identified Space Effort parameters with respect to p-value < 0.05 for Punch (p = 0.0408), Dab (p = 0.0302), and Glide (p = 0.0273) visualizations. For the Time Effort parameter, there is a significant difference among systems with respect to p-value < 0.05 for Dab (p = 0.0388), Glide (p = 0.0388), Wring (p = 0.0498), and Float (p = 0.0208) visualizations. For the Weight Effort parameter, there is a significant difference among systems with respect to p-value < 0.05 for Dab (p = 0.0074), Slash (p = 0.0302), and Float (p = 0.0342) visualizations. These results reject a null hypothesis. Thus, participants were not able to equally recognize and identify Effort parameter values meant to represent Basic-Effort-Actions visualizations because there is a significant difference among systems.

To answer the second part of RQ2, CMH pairwise comparisons among systems were performed for Space, Time, and Weight to compare the percentage of correct Effort parameter values identification for systems A and B, A and C, and C and B, respectively. This was done to identify the source of significance and detect whether two systems were different regardless of which one performed better. Table 6.6 presents the results from CMH pairwise comparisons.
Table 6.6. Cochran-Mantel-Haenszel test results for correctly identified Effort parameter values for each Basic-Effort-Action visualization. (a) Space, (b) Weight, (c) Time.

<table>
<thead>
<tr>
<th>BEA Visualization</th>
<th>SPACE Effort</th>
<th>DF</th>
<th>Value</th>
<th>Prob</th>
<th>Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Punch</td>
<td>A versus B</td>
<td>1</td>
<td>4.0000</td>
<td>0.0455</td>
<td>B (33.3%) &amp; C (33.3%) &gt; A (0%)</td>
</tr>
<tr>
<td></td>
<td>A versus C</td>
<td>1</td>
<td>4.0000</td>
<td>0.0455</td>
<td></td>
</tr>
<tr>
<td></td>
<td>B versus C</td>
<td>1</td>
<td>0.0000</td>
<td>1.0000</td>
<td>B = C</td>
</tr>
<tr>
<td>Dab</td>
<td>A versus B</td>
<td>1</td>
<td>4.0000</td>
<td>0.0455</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A versus C</td>
<td>1</td>
<td>5.0000</td>
<td>0.0253</td>
<td>A (50%) &gt; B (16.7%) &amp; C (8.3%)</td>
</tr>
<tr>
<td></td>
<td>B versus C</td>
<td>1</td>
<td>0.3333</td>
<td>0.5637</td>
<td>B = C</td>
</tr>
<tr>
<td>Glide</td>
<td>A versus B</td>
<td>1</td>
<td>0.0000</td>
<td>1.0000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A versus C</td>
<td>1</td>
<td>6.0000</td>
<td>0.0143</td>
<td>A (50%) &amp; B (50%) &gt; C (0%)</td>
</tr>
<tr>
<td></td>
<td>B versus C</td>
<td>1</td>
<td>6.0000</td>
<td>0.0143</td>
<td></td>
</tr>
</tbody>
</table>

(a.)

<table>
<thead>
<tr>
<th>BEA Visualization</th>
<th>WEIGHT Effort</th>
<th>DF</th>
<th>Value</th>
<th>Prob</th>
<th>Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dab</td>
<td>A versus B</td>
<td>1</td>
<td>5.4444</td>
<td>0.0196</td>
<td>B (75%) &gt; A (16.7%)</td>
</tr>
<tr>
<td></td>
<td>A versus C</td>
<td>1</td>
<td>0.0000</td>
<td>1.0000</td>
<td>A = C</td>
</tr>
<tr>
<td></td>
<td>B versus C</td>
<td>1</td>
<td>7.0000</td>
<td>0.0082</td>
<td>B (75%) &gt; C (16.7%)</td>
</tr>
<tr>
<td>Slash</td>
<td>A versus B</td>
<td>1</td>
<td>4.5000</td>
<td>0.0339</td>
<td>B (66.7%) &gt; A (16.7%)</td>
</tr>
<tr>
<td></td>
<td>A versus C</td>
<td>1</td>
<td>1.0000</td>
<td>0.3173</td>
<td>A = C</td>
</tr>
<tr>
<td></td>
<td>B versus C</td>
<td>1</td>
<td>4.0000</td>
<td>0.0455</td>
<td>B (66.7%) &gt; C (33.3%)</td>
</tr>
<tr>
<td>Float</td>
<td>A versus B</td>
<td>1</td>
<td>1.8000</td>
<td>0.1797</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A versus C</td>
<td>1</td>
<td>1.8000</td>
<td>0.1797</td>
<td>A = C</td>
</tr>
<tr>
<td></td>
<td>B versus C</td>
<td>1</td>
<td>6.0000</td>
<td>0.0143</td>
<td>B (83.3%) &gt; C (33.3%)</td>
</tr>
</tbody>
</table>

(b.)

<table>
<thead>
<tr>
<th>BEA Visualization</th>
<th>TIME Effort</th>
<th>DF</th>
<th>Value</th>
<th>Prob</th>
<th>Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dab</td>
<td>A versus B</td>
<td>1</td>
<td>4.0000</td>
<td>0.0455</td>
<td>A (100%) &gt; B (66.7%)</td>
</tr>
<tr>
<td></td>
<td>A versus C</td>
<td>1</td>
<td>1.0000</td>
<td>0.3173</td>
<td>A = C</td>
</tr>
<tr>
<td></td>
<td>B versus C</td>
<td>1</td>
<td>3.0000</td>
<td>0.0833</td>
<td>B = C</td>
</tr>
<tr>
<td>Glide</td>
<td>A versus B</td>
<td>1</td>
<td>1.0000</td>
<td>0.3173</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A versus C</td>
<td>1</td>
<td>4.0000</td>
<td>0.0455</td>
<td>A (100%) &gt; C (66.7%)</td>
</tr>
<tr>
<td></td>
<td>B versus C</td>
<td>1</td>
<td>3.0000</td>
<td>0.0833</td>
<td>B = C</td>
</tr>
<tr>
<td>Wring</td>
<td>A versus B</td>
<td>1</td>
<td>4.0 00</td>
<td>0.0455</td>
<td>A (100%) &gt; B (66.7%) &amp; C (58.3%)</td>
</tr>
<tr>
<td></td>
<td>A versus C</td>
<td>1</td>
<td>5.0000</td>
<td>0.0253</td>
<td></td>
</tr>
<tr>
<td></td>
<td>B versus C</td>
<td>1</td>
<td>0.2000</td>
<td>0.6547</td>
<td>B = C</td>
</tr>
<tr>
<td>Float</td>
<td>A versus B</td>
<td>1</td>
<td>5.0000</td>
<td>0.0253</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A versus C</td>
<td>1</td>
<td>6.0000</td>
<td>0.0143</td>
<td></td>
</tr>
<tr>
<td></td>
<td>B versus C</td>
<td>1</td>
<td>0.2000</td>
<td>0.6547</td>
<td></td>
</tr>
</tbody>
</table>

(c.)

Note. The significant results for each Effort parameter are highlighted in grey. A = EMVIZ (Motion-Agent), B = EMVIZ (Sketch), and C = EMVIZ (L). Greater-than sign (>) means "performs greater than." Equals sign (=) means "no difference." Percentage (%) refers to system’s precision presented in Figure 6.3. See a descriptive explanation for CMH pairwise comparisons test in Appendix C, section 3.2.1 – 3.2.3. See the result of data analysis from SAS software in Appendix C, section 1 (Pairwise CMH results.rtf).

To summarize the results for RQ2, the Effort parameter values for each Basic-Effort-Action visualization among three EMVIZ systems were not equally recognized by participants because there is a significant difference among systems in correctly identified Space Effort parameter for Punch, Dab, and Glide visualizations,
Weight Effort parameter for Dab, Slash, and Float visualizations, and Time Effort parameter for Dab, Glide, Wring, and Float visualizations. Table 6.8’s summary column summarizes which Effort parameters and Basic-Effort-Action visualization among three systems is significantly different and performs better than others.

To answer RQ3, “Is there a difference in mean number among systems for correctly matching Basic-Effort-Actions visualizations and correct Effort parameter values (Space, Time, Weight) identification?”, the eight Basic-Effort-Actions visualizations within each system were defined as the experimental unit, while the system itself was defined as the explanatory variable or independent variable. The number of correct matches and correctly identified Effort parameter values for each Basic-Effort-Action visualization were defined as the responsive variable. The participant was used as a block variable.

To perform the One-way ANOVA or F-test, the statistical assumption must be checked (i.e., the variances for treatments [3 systems] need to be equal). Therefore, a likelihood ratio test (LR)⁴ was performed to test the significance level or the possibility of unequal variances of mean numbers for (a) correctly matched Basic-Effort-Actions visualizations and (b) correctly identified Effort parameter values (Space, Time, Weight) among systems. There was evidence of significant differences among systems for Time Effort parameter values identification, but not for correctly matched Basic-Effort-Actions visualizations and correct identification of Space and Weight Effort parameter values⁵. This means the variances for treatments (three systems) are not equal. One assumption is that the response variables are normally distributed, violating the assumption of equal variances for treatments⁶. Therefore, One-way ANOVA or F-test is not an appropriate model to use in this analysis. Thus, the data was refitted with different variances for the systems. One-way blocked analysis of variance (ANOVA⁷), using up to two degrees of

---

⁴ Likelihood Ratio is a statistical test used to test null hypothesis against alternative hypothesis. See: http://www.statistics.com/index.php?page=glossary&term_id=787

⁵ See: LR Table in Appendix C, section 4.

⁶ F-Test is generally not robust when there are violations of the assumption that each population follows the normal distribution. See: http://www.jstor.org/stable/1170363 or http://en.wikipedia.org/wiki/F-test_of_equality_of_variance.

⁷ One-way blocked analysis of variance is the analysis of variance test that includes participants as a random effect. See: http://www.basic.northwestern.edu/statguidefiles/oneway_b_anova.html.
freedom for testing system effect, was used to test for differences in mean numbers for (a) correctly matched Basic-Effort-Actions visualizations and (b) correctly identified Effort parameter values for each Basic-Effort-Action visualization among systems using the participant as a block variable. Table 6.7 presents ANOVA or F-test results.

**Table 6.7.** F-Test for difference in mean numbers of (a) correctly matched Basic-Effort-Actions visualizations and (b) correctly identified Effort parameter values for each Basic-Effort-Action visualization among systems

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Effect</th>
<th>NumDF</th>
<th>DenDF</th>
<th>FValue</th>
<th>ProbF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Match System</td>
<td>System</td>
<td>2</td>
<td>33</td>
<td>2.49</td>
<td>0.0983</td>
</tr>
<tr>
<td>Space System</td>
<td>System</td>
<td>2</td>
<td>22</td>
<td>2.75</td>
<td>0.0862</td>
</tr>
<tr>
<td>Weight System</td>
<td>System</td>
<td>2</td>
<td>22</td>
<td>4.57</td>
<td>0.0219</td>
</tr>
<tr>
<td>Time System</td>
<td>System</td>
<td>2</td>
<td>13</td>
<td>9.32</td>
<td>0.0031</td>
</tr>
</tbody>
</table>

Note. The significant results for each Effort parameter are highlighted in grey. Match = Correctly matched Basic-Effort-Actions visualizations, Space = Correctly identified Space, Weight = Correctly identified Weight, Time = Correctly identified Time. NumDF = Records the degrees of freedom in the numerator for each test. DenDF = Records degrees of freedom used in the denominator for each test. Fvalue = Records a calculated F statistic for each test. ProbF = Probability of obtaining an F value larger than the one calculated if in reality the variances are equal across all levels. See the result of data analysis from SAS software in Appendix C, section 1 (Anova_F-test_pairwise results.rtf).

F-test results indicated that there is a significant difference in mean number of correctly identified Weight and Time Effort parameter values with respect to p-value (p = 0.0219 and 0.0031, respectively). The mean number of correctly matched Basic-Effort-Actions visualizations and correctly identified Space is nearly significant because their p-values were less than 0.1. This suggests that the three EMVIZ systems equally communicate movement quality and that participants equally identified Space Effort parameter values.

However, Weight and Time Effort parameter values for each Basic-Effort-Action visualization among systems were unevenly identified by participants. As a result, T-tests for pairwise comparisons were performed to identify the significance’s source and to detect whether two systems were different regardless of which one performed better.

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8 See: http://jmp.com/support/help/Unequal_Variances.shtml
Table 6.8 presents T-tests for pairwise comparisons. Table 6.9 presents least squares mean number of correctly matched visualizations and correctly identified Effort parameter values by system.

### Table 6.8. T-tests for pairwise comparisons among systems.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Comparison</th>
<th>Estimate</th>
<th>StdErr</th>
<th>DF</th>
<th>tValue</th>
<th>Probt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>System A vs B</td>
<td>-0.9167</td>
<td>0.6626</td>
<td>22</td>
<td>-1.38</td>
<td>0.1804</td>
</tr>
<tr>
<td>Weight</td>
<td>System A vs C</td>
<td>1.0833</td>
<td>0.6626</td>
<td>22</td>
<td>1.64</td>
<td>0.1163</td>
</tr>
<tr>
<td>Weight</td>
<td>System B vs C</td>
<td>2.0000</td>
<td>0.6626</td>
<td>22</td>
<td>3.02</td>
<td>0.0063</td>
</tr>
<tr>
<td>Time</td>
<td>System A vs B</td>
<td>1.4167</td>
<td>0.3596</td>
<td>10.9</td>
<td>3.94</td>
<td>0.0023</td>
</tr>
<tr>
<td>Time</td>
<td>System A vs C</td>
<td>1.5833</td>
<td>0.6669</td>
<td>11.2</td>
<td>2.37</td>
<td>0.0365</td>
</tr>
<tr>
<td>Time</td>
<td>System B vs C</td>
<td>0.1667</td>
<td>0.7293</td>
<td>13.3</td>
<td>0.23</td>
<td>0.8227</td>
</tr>
</tbody>
</table>

Note. The significant results for each Effort parameter are highlighted in grey. Characteristic = Three Effort factors (Space, Weight, and Time). Comparison = Comparison of significant level among 3 EMVIZ systems (A, B, and C). Estimate = Value of the estimated difference between the two X levels. StdErr = Lists the estimates of the standard deviations for the group means. tValue = Value of the t-statistic. Probt = The p-value. See the result of data analysis from SAS software in Appendix C, section 1 (Anova_F-test_pairwise results.rtf).

### Table 6.9. Least squares mean number of correctly matched visualizations and correctly identified Effort parameter values by system.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>System</th>
<th>Estimate</th>
<th>StdErr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Match</td>
<td>A</td>
<td>3.83</td>
<td>0.4511</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>4.41</td>
<td>0.4511</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>3.00</td>
<td>0.4511</td>
</tr>
<tr>
<td>Space</td>
<td>A</td>
<td>3.58</td>
<td>0.4911</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>3.16</td>
<td>0.4911</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>2.41</td>
<td>0.4911</td>
</tr>
<tr>
<td>Weight</td>
<td>A</td>
<td>3.83</td>
<td>0.6893</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>4.75</td>
<td>0.6893</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>2.75</td>
<td>0.6893</td>
</tr>
<tr>
<td>Time</td>
<td>A</td>
<td>7.33</td>
<td>0.3180</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>5.91</td>
<td>0.4338</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>5.75</td>
<td>0.7097</td>
</tr>
</tbody>
</table>

Note. Match = Correctly matched Basic-Effort-Actions visualizations, Space = Correctly identified Space, Weight = Correctly identified Weight, Time = Correctly identified Time. See the result of data analysis from SAS software in Appendix C, section 1 (Anova_F-test_pairwise results.rtf).
T-tests for pairwise comparisons show that the means of Weight Effort parameter values for systems B and C differ significantly (p=0.0063) and that the mean for system B (4.75) is larger than system C (2.75) (Table 6.9). There is also a significant difference for Time Effort parameter values for systems A and B (p = 0.0023) and systems A and C (0.0365), where the mean for system A (7.33) is larger than for system B (5.91) and C (5.7.5) (see Table 6.9). To summarize, the communicative ability of Weight Effort for system B is better than system C and the communicative ability of Time Effort for system A is better than systems B and C.

To summarize, Table 6.10 presents all answers corresponding to RQ1-RQ3.

### Table 6.10. Summary for RQ1-RQ3

<table>
<thead>
<tr>
<th>Research Questions and Answers</th>
<th>Effort parameter (Space, Weight, Time) for each Basic-Effort-Action visualization?</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RQ1.</strong> Is there a difference among systems in correct matching between Basic-Effort-Actions movement sequences and Basic-Effort-Actions visualizations?</td>
<td>The eight Basic-Effort-Actions visualizations generated by three EMVIZ systems were not equally able to communicate the movement quality they are intended to convey because there is a significant difference among systems in correctly matched Basic-Effort-Actions movement sequences with Basic-Effort-Actions visualizations for Punch, Slash, Flick, Glide, and Wring.</td>
</tr>
<tr>
<td>If there is a significant difference, which visualization among systems is significantly different and performs better than the others?</td>
<td>• For Punch, Slash, and Flick visualizations, system B &gt; A.</td>
</tr>
<tr>
<td></td>
<td>• For Glide visualization, system A &amp; B &gt; C.</td>
</tr>
<tr>
<td></td>
<td>• For Wring visualization, system A &gt; B.</td>
</tr>
<tr>
<td><strong>RQ2.</strong> Is there a difference among systems in correct identification of Effort parameter values (Space, Weight, Time) for each Basic-Effort-Action visualization?</td>
<td>The Effort parameter values for each Basic-Effort-Action visualization among three EMVIZ systems were not equally recognized by participants because there is a significant difference among systems in correctly identified Space Effort parameter for Punch, Dab, and Glide visualizations, Weight Effort parameter for Dab, Slash, and Float visualizations, and Time Effort parameter for Dab, Glide, Wring, and Float visualizations.</td>
</tr>
<tr>
<td>If there is a significant difference, which Effort parameter (Space, Weight, Time) is significantly different and performs better than others?</td>
<td>• <strong>Space:</strong> Punch (system B &amp; C &gt; A), Dab (system A &gt; B &amp; C), Glide (system A &amp; B &gt; C)</td>
</tr>
<tr>
<td></td>
<td>• <strong>Weight:</strong> Dab and Slash (system B &gt; A &amp; C), Float (system B &gt; C)</td>
</tr>
<tr>
<td></td>
<td>• <strong>Time:</strong> Dab (system A &gt; B), Glide (system A &gt; C), Wring and Float (system A &gt; B &amp; C)</td>
</tr>
</tbody>
</table>
Research Questions and Answers

RQ3. Is there a difference among systems in mean number for correct matching of Basic-Effort-Action visualizations and correct Effort parameter values identification?

- Three EMVIZ systems equally communicate movement quality and participants equally identified Space Effort parameter values. However, Weight and Time Effort parameter values for each Basic-Effort-Action visualization among systems were unevenly identified by participants because there is a significant difference in mean number of correctly identified Weight and Time Effort parameters.

- The communicative ability of Weight Effort for system B is better than system C and the communicative ability of Time Effort for system A is better than systems B and C.

Note. A = EMVIZ (Motion-Agent), B = EMVIZ (Sketch), and C = EMVIZ (L). Greater-than sign (>) means “significantly difference and performs greater than.”

6.4. Feedback on Three EMVIZ Systems

This section summarizes open-ended questions asked of participants, which were intended to facilitate participant feedback on their experience of all visualizations generated by three EMVIZ systems (see Appendix C, section 5). In this analysis process, I include feedback from three participants who did not complete the survey because their comments are very useful and informative. To investigate participant feedback, content analysis was applied to segment and categorize similar answers among three visualization systems. The analysis results show that there are two primary problems for systems A and B regarding visual perception and communication: (1) multiple foci in visualization and (2) multiple Effort parameter values presented in the visualization. System C, on the other hand, has some problems regarding the abstractness and speed of the visualization (see section 6.4.3).

Regarding the multiple foci in visualization, participants reported that they had a hard time identifying the quality of the visualization (i.e., the eight Basic-Effort-Actions).

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9 Two participants completed 75% of the survey, while one participant completed 50% of the survey. See more details in survey summary in Appendix B, section 4.

They were confused about which part of the visualization to focus on in order to identify the eight Basic-Effort-Actions. Figure 6.6 illustrates this issue reported by participants.

**Figure 6.6. Example of multiple foci for identifying Punch visualization generated by system A**

In Figure 6.6, a group of grey-coloured flocking agents (i.e., moving particles) wander around the space representing random motion patterns (upper left). This random motion pattern appears when there is no Basic-Effort-Action detected by a sensor on the wrist of a dancer (lower left). The group of flocking agents changes colour and motion pattern (middle top) according to Punch quality detected by a sensor (middle bottom). Afterwards, the red-orange colour fades to grey and the group of flocking agents return to a random motion pattern (upper right). These three phases of movement and visualization confused some participants as to which motion or visualization elements to focus on in order to identify the eight Basic-Effort-Actions.

This problem is linked with a second issue regarding the multiple Effort parameter values presented in the visualization. In general, several participants reported that they had a hard time identifying Effort parameter values because some visualizations contained two Effort parameter values (e.g., Sudden and Sustained). For instance, in the Press visualization, a group of particles quickly moves toward centre and slowly dissipates outward from the centre. Some participants pointed out that this motion pattern or visualization can be perceived as Direct and Sudden when a group of particles quickly moves toward the centre. However, it can also be perceived as Indirect and Sustained when all particles slowly dissipate outward from centre. This contradiction made some participants unable to identify a single Effort parameter value present in a visualization (i.e., in task 2 of the questionnaire) although they were able to correctly
identify the Basic-Effort-Actions visualization in task 1 of the questionnaire. These two main communication problems are discussed further in comparative analysis (Chapter 7).

The following sections describe feedback for each EMVIZ system. Each section begins with feedback on the overall clarity of visualization followed by Space and Time Effort feedback and finally, feedback on Weight Effort in association with visual appearance and colour.

6.4.1. **System A: EMVIZ (Motion-Agent)**

Two participants reported that overall visualization communication was clear or fine while four participants reported that it was hard to identify Basic-Effort-Actions or recognize quality of the visualization. One participant reported that some visualization were very clear for communicating movement qualities (i.e., Basic-Effort-Actions) but some were not. Participants described their experience as follows:

<table>
<thead>
<tr>
<th>ID</th>
<th>Feedback</th>
</tr>
</thead>
<tbody>
<tr>
<td>ID11</td>
<td>Over all, the clarity of communication was quite positive, I think.</td>
</tr>
<tr>
<td>ID50</td>
<td>Generally clear overall. Communication was fine.</td>
</tr>
<tr>
<td>ID9</td>
<td>The correlations of the visualization to the actual movement sequences was difficult for me to draw conclusions about. I must say that drawing conclusions about connections was a bit of a guessing game for me. The movement sequences were crystal clear; the visualization had cloudy elements.</td>
</tr>
<tr>
<td>ID14</td>
<td>Some Basic Effort Actions were very clear in this method. Some seemed left up to interpretation and more difficult to convey.</td>
</tr>
<tr>
<td>ID20</td>
<td>Overall, the images were difficult for me to actually match to the BEA's.</td>
</tr>
<tr>
<td>ID35</td>
<td>Visualizations seem to attempt to poetry recuperation from the basic effort action which can be confusing. I see lots of overlap and room for interpretation....not completely objective by any means.</td>
</tr>
<tr>
<td>ID38</td>
<td>I found it very difficult for system A to depict qualities that are human.</td>
</tr>
</tbody>
</table>

The two main problems of system A are the multiple foci in visualization and the multiple Effort parameter values presented in the visualization. Participants described their experience regarding the multiple foci in visualization as follows:
ID11: I had to decide which part of the sequence I should focus on to identify the BEA. (I assume that it is because the original movement sequence was so).

ID26: I was just guessing because these visualizations are actually phrases, not actions. I was not sure which portion of the phrase was meant to represent the BEA.

ID33: The challenge was to know what was the beginning of the phrase and what was the end.

ID40: It was also hard to 'match' to BEA's because each visualization seems to be a phrase of several parts (often 3 parts, beginning, middle and end).

From participant perspectives, Space and Time Effort seemed to be the most confusing and difficult to identify according to the multiples Effort parameter values presented in the visualization. Participant comments were as follows:

**Space**

ID11: For Space Effort, it was a little confusing for me to deal with both movements: the movement as a whole and the movement as an each part. For instance, some visualizations had a moment of "bursting" coming out from the center, and it seemed Indirect Space because the parts came out to all over the space with multi-fociuses, but at the same time, the visualization of the trace of each part was so Direct in Space.

ID44: There were some animations that both condensed and spread, so I wasn't sure which part to focus on. In other words those looked both Direct and Indirect, so I said neither.

ID52: The particles seem Indirect before/after the action in general, and the follow through after the action was sometimes hard to discern/separate from the action.

**Time**

ID18: The particles seem Indirect before/after the action in general, and the follow through after the action was sometimes hard to discern/separate from the action.

ID19: Time was harder and depended upon what part of the phrase I was paying attention to - it was sometimes hard to distinguish accelerating/decelerating from Sudden/Sustained.

ID28: Dynamics are unclear, dynamics are contradictive. For example, both sustained and sudden are included in several visualizations. Relativity is a big factor for me.

ID40: This made it hard for me to list just one quality, as one visualization might start with suddenness, sustain in the middle, then accelerate at the end.

This issue is reflected by a low percentage of correctly identified Space Effort parameter (i.e., 44.8% [Direct 37.5% and Indirect 52%]; see Appendix C, section 2.3.7).
The percentage of correctly identified Time Effort parameter values was high (i.e., 88.6% [Sudden 91.7% and Sustained 85%]), although some participants reported that they had a hard time identifying Time Effort. This is probably because Time Effort is the most salient motion feature that humans are able to perceive easily, as stated by some participants (e.g., ID11: “dynamics certainly worked and visual appearance seemed to be very clear with Time Effort”; ID 56: "the dynamics in the light movement were the most powerful").

In regards to visual appearance and colour code in association with Weight Effort, participants reported that (1) they did not pay attention or they used visual element and colour as criteria for identifying the eight Basic-Effort-Actions and (2) they could not see the association between visual element and colour, and any Effort parameter values. To identify Weight, they focused on the overall differences in motion quality rather than referring to the colour code. These two issues are reflected by a low average percentage of correctly identified Weight Effort parameter values (i.e., 46.9% [Strong 43.7% and Light 50%]).

Participant feedback on visual appearance and colour code in association with Weight Effort was described as follows:

**Weight**

*ID9*: I did not associate the colors with the Efforts, except for purple which seemed to have a Strong Weight quality I must say that drawing conclusions about connections was a bit of a guessing game for me.

*ID11*: To me, color didn't matter at all. Visual appearance not quite clear with Weight Effort as it sometimes became recognizable associated with other Effort elements.

*ID14*: I did not distinguish by color when I was observing the visualizations. I looked for qualitative differences in the movement of the patterns on the screen.

*ID19*: I could not gather a sense of weight effort.

*ID28*: It was hard to read for weight and I think I inferred and guessed weight on those due to the totality of the visualization.

*ID38*: The color denoted the action but was difficult to follow it.

*ID40*: It was difficult for me to observe weight. Weight was not something I could observe with this system.

*ID 50*: Colour scheme more challenging to interpret the BEA.
In mapping the design process, the object size and colour code assigned for each Basic-Effort-Action were originally designed to enhance and support Weight Effort parameter values identification. For instance, increasing object size and colour saturation represented Strong Weight while decreasing size of the object and colour saturation represented the opposite. However, the majority of participants did not recognize Weight based on size, colour code or colour saturation. This is probably due to the following reasons:

- Participants (CMAs) were trained to focus on and analyze human motion patterns. Thus, they paid greater attention to motion pattern than to other elements.
- The subjectivity of colour perception may be another factor in why participants did not associate Weight Effort with colour.
- Participants did not clearly see the transition of object size and colour saturation in the visualization.

However, some participants were influenced by colour when identifying Weight Effort parameter values. They reported that colour was sometimes helpful for identifying Weight Effort parameter values. Participant comments were as follows:

- **ID16**: Visual appearance: colour seems to distinguish elements of phrasing but is sometimes misleading.
- **ID35**: Red Color is helpful in indicating strength.
- **ID43**: I think associate certain colors with more strength. Red looked Stronger. Pastel blue looked Lighter. Purple could go either way. Yellow, Green, and Orange were hard to perceive weight through.

### 6.4.2. System B: EMVIZ (Sketch)

Three participants reported that system B’s overall visualization communication was clearer than system A, while five participants reported that system B’s output visualization was more difficult for Basic-Effort-Action identification than system A. Participants described their experience as follows:
**ID26:** System B seems more clear than System A on Space and Weight.

**ID38:** The whole visual appearance was much clearer.

**ID50:** This system seems clearer to me in terms of revealing the individual effort elements.

**ID9:** My reactions are much like those of section 2. There was difficulty in matching BEAs to the visualizations.

**ID11:** In general, my impression was that System B was more abstract while System A was more representational, and it was much harder (and confusing) to identify BEA through System B. With System A, viewing each visualization was enough to figure out each Effort Action along with its own Effort configuration, but with System B, I had to view many of the visualizations over and over again to compare each other and get a relative sense of how each Effort element was realized in the different visualizations.

**ID14:** I found this system a little frustrating.

**ID35:** Even more frustrating. Not clear at all that each visualization was meant to match ONE basic effort action? Lots of guessing here.

**ID56:** These examples were not as clear for me to ascertain the effort qualities.

The three participants who reported clear overall visualization had correctly identified the eight Basic-Effort-Actions visualizations in system B with an average of 66.6%, while the five participants who reported difficulty with the overall visualization communication correctly identified Basic-Effort-Actions visualizations with an average of 70% (see data-listing-analysis.rtf in Appendix B, section 3). This result shows that even though some participants had a hard time identifying the eight Basic-Effort-Actions in system B, they were able to correctly identify Basic-Effort-Actions visualization with a good average percentage (55.2%) compared to system A (47.9%) (See Appendix C, section 2.3.1 – 2.3.2). This issue is discussed further in comparative analysis (Chapter 7).

From participant perspectives, system B had similar problems regarding visualization communication compared to system A. The issues were the multiple foci in visualization and multiple Effort parameter values presented in the visualization. However, the majority of participants seemed to have more problems with multiple Effort parameter values than with multiple foci. Space and Time Efforts were the most confusing among the three Effort parameters. Participants described their experiences
as follows:

**Space**

**ID14:** This also happened for me with pace effort- the shapes' trajectory would seem to use direct space yet it would move in an indirect way on that direct path.

**ID19:** The Space was harder to see in these. Visualization 6 felt like both a Press and a Glide to me - a Press on the way in and a Glide on the way out.

**ID16:** Space was ambiguous in a few places, for example, Glide had multiple initiation points, so to make it more direct the blue dots can converge more.

**ID40:** The fact that each visualization had a phrase that often included a 'recuperation' moment of the opposite element from the main statement helped me match the phrases to the dancer's BEAs (3.1), but made it harder to say in 3.2 only one of each polarized element--perhaps if the question had been about the main statement, or the majority of time, I would only have listed one of the polarized elements.

**Time**

**ID11:** I had the same problem with System B in terms of deciding which moment of the sequence I should focus on for the identification because shift happens in a moment. For example, the circular bubble-like shapes would move in a trail that seemed to use sustained time but the individual shapes would appear on the screen quickly.

**ID16:** Time was ambiguous in a few places. Visualization 7 was indiscernible for me: it contains quick initiations but sustained afterwards, starting from one point and radiating outwards - so it is simultaneously sudden/sustained, direct/indirect. Visualization 6 is also ambiguous - it converges, making it direct, but also accelerates. The acceleration makes it seem like it is "about" Time effort, but it is not sustained or sudden because it actually progresses from sustained to sudden.

**ID28:** Again, most visualizations included both quick and sustained, and strong and light. Time seemed the clearest.

This issue was reflected in the low average percentage of correctly identified Space Effort parameter (i.e., 39.6% [Direct 31.3% and Indirect 47.9%]) (See Appendix C, section 2.3.8). Some participants reported that they identify Space Effort through transition of overall shape, direction, and visual pattern (see below).
Once I assigned meaning to the bubbles vs the lines and popping vs. the unfolding, I had a system for decoding. The bubbles vs. lines useful for space.

System B was easier to see spatially, the change in shapes of the visualizations also added to the understanding such as the circles for dab.

Concentric direction, or unified direction was more perceived as direct, eccentric directions and diverse directions of elements were perceived as Indirect by me.

Unlike Space Effort, Time Effort had a better average percentage of correctly identified Sudden Time at 81.3% and Sustained Time at 66.7% (See Appendix C, section 2.3.8). This issue had a negative impact on the average percentage of correctly identified Time Effort parameter values. System B should have a better average percentage of correctly identified Time Effort because Time Effort is the most salient motion feature that humans should be able to perceive, including in abstract animation or visualization.

For the Weight Effort parameter, three participants reported that they could not perceive Weight Effort but four participants reported that system B seemed to be easier than system A for recognizing Weight Effort through the transition of size, colour code, and colour saturation. From usability testing results, system B had a better average percentage of correctly identified Weight Effort parameter (i.e., 59.4% [Strong 50% and Light 68.8%]) than system A (i.e., 46.9% [Strong 43.7% and Light 50%]), especially Light Weight Effort (see Appendix C, section 2.37 - 2.38). However, system B still had some problems with Weight Effort representation (see further discussion in comparative analysis, Chapter 7). Participants described their experience as follows:
**Weight**

*ID16:* Weight is not presented.

*ID38:* Color did not seem to be a factor for me.

*ID40:* It was hard to perceive weight in the visualizations.

*ID11:* Some of the visualization worked with color this time, for instance, like giving a sense of Strong Weight through gradually darkening the color in the same tone.

*ID20:* The color and dynamics were very useful for weight and time.

*ID28:* It seems like size begins to represent weight (large image for strong and small image for light).

*ID33:* The ways in which the circles collided on one another, the brilliance of the colors were my determining factors.

6.4.3. **System C: EMVIZ (L)**

For system C, nearly all participants reported that overall visualization communication was not clear for communicating movement quality (i.e., eight Basic-Effort-Actions). Because of the abstractness of the overall shape, it was hard to identify Space, Weight, and Time Effort. This issue confused some participants and they guessed the quality of the visualization. Weight Effort was identified through colour code and colour saturation, while Time Effort was identified through the quickness or slowness of the animation. Space Effort was not presented or recognized in the visualization. System C seemed to be the most problematic of the EMVIZ systems for representing movement quality. Unlike systems A and B, system C had unclear Effort parameter values representation because of the abstractness and the quickness of the visualization. Participants described their overall experiences as follows:

*ID9:* Instead of thinking of the Action Drive, I tried to identify Efforts in the visualizations first. Again, however, this was a guessing game for me.

*ID11:* The visualization of System C wasn't quite effective for me to identify the BEA. In general, System C was the hardest to communicate BEA through the visual representations.

*ID14:* It was really difficult to determine any clarity.

*ID20:* Overall, the clarity of communication was confusing for relating to the BEA’s.

*ID28:* Clarity of communication was unclear.
**ID33:** Highly subjective as I found the "lines" to be dictating. Phrasing, that is where lines began and where ended, were my guides.

**ID38:** These were nearly impossible for me to detect and I probably guessed on most of these. Because of time constraints on my part I could not spend a great deal of time looking at this one and it frustrated me.

**ID40:** I didn't actually match the dancer to the visualizations but since the questionnaire won't let me go on without answering, I put in the values from previous systems, so my answers here really have NO BEARING on this visualization system.

**ID56:** These examples were also not as clear to me as the first set.

System C had the lowest average percentage for communicating all movement quality (42.4%) compared to systems A and B. It also had a very low percentage of correctly identified Space Effort (i.e., 20.9% [Direct 12.5% and Indirect 52%]) (see Appendix C, section 2.39). For Space and Time Effort, participants described their experiences as follows:

**Space**

**ID11:** Space Effort was the most confusing to me in terms of how to differentiate Direct from Indirect because most of them looked Indirect with the on/off kind of movement of clusters here and there.

**ID20:** This one was much harder for me to find the space effort.

**Time**

**ID11:** The Time effort was actually "slow" or "fast" with Even phrasings rather than "Quick" or "Sustained" in the sense of Time factor in Effort.

**ID19:** In visualization 6, it was the lingering after image that made me feel Sustainment - this was the only one that felt at all sustained to me.

**ID28:** Dynamics were not clear or there were multiple effort actions within each visualization.

**ID35:** All visualizations were variations of the same thing except number 8 which only varied in color and therefore gave me indication of STRONG. However I don't think everyone would have that interpretation.

**ID40:** I couldn't perceive differences in LMA terms in this system other than some were slightly more sudden than others.

Although participant feedback indicated that system C had some problems in communicating Time Effort, the overall average percentage of correctly identified Time
Effort was still good (71.9%). The majority of participants were able to correctly identify Sudden Time at the average percentage of 85.4%. However, they were only able to correctly identify Sustained Time at the average percentage of 58.3% (see Appendix C, section 2.39). This result shows that system C somewhat failed to communicate Sustained Time, even though Time Effort is the most distinct motion feature that humans should be able to easily perceive (see further discussion in comparative analysis, Chapter 7).

For Weight Effort, it was also hard for participants to identify Strong or Light Weight because of the visualization’s overall abstractness and quickness. Some participants tried to identify Weight Effort from the changes of visual variables such as line length or stroke weight. However, system C had the lowest overall average percentage for communicating Weight Effort (34.4%) compared to systems A and B. It also had a very low percentage of correctly identified Weight Effort (i.e., Strong 35.4% and Indirect 33.3%; see Appendix C, section 2.39). This is probably due to the following reasons:

- The subjectivity of colour perception;
- Unclear visual transition (e.g., stroke weight);
- Abstractness and quickness of the visualization;

These issues are discussed further in comparative analysis (Chapter 7). Participants described their experiences regarding Weight Effort representation as follows:
Weight

ID11: I interpreted Weight factor with more primary colors for Strong Weight and more pale colors for Light Weight, but it seemed a little arbitrary because the visualization itself didn’t really give me a sense of Weight through the movement of the image and I tried to match the particular Effort factor with any component that could be encoded someway.

ID14: It was extremely difficult to read weight in this system.

ID19: In visualization 5, it was the softness of the color that made me think of Light Weight. In visualization 7, it was the length of the lines that gave me the feeling of Strong Weight, while in visualization 1 it was the width of the lines that gave me that feeling. Weight Efforts were hard to distinguish.

ID20: The color allowed me to discover strength, the visual appearance seemed to suggest weight and the dynamics time.

6.4.4. Summary

To summarize, systems A and B have two primary issues regarding visualization perception and communication: (1) multiple foci in visualization and (2) multiple Effort parameter values presented in the visualization. System C’s main problems, on the other hand, are the abstractness and the quickness of the visualization. These problems are reflected in low average percentages of overall movement quality (i.e., the eight Basic-Effort-Actions) and Effort parameter values identification (i.e., Space, Weight, and Time). All EMVIZ systems also have issues with Weight Effort identification because some participants did not use the changes of visual variables (e.g., size, colour code or colour saturation) as criteria for identifying the eight Basic-Effort-Actions and their Effort parameter values. The subjectivity of colour or cross-cultural colour perception could be another factor leading to incorrect movement quality and Effort parameter values identification. Figure 6.7 presents a summary diagram of participant feedback for three EMVIZ systems.
Figure 6.7. A summary diagram of participant feedback for three EMVIZ systems

For the online survey format, participants suggested that matching visualizations and movement sequences side-by-side might have made the process of Basic-Effort-Action visualization identification clearer. This is because participants had to watch each visualization video and each movement video in two separated windows and some participants may have had difficulty finding linkage between phases in visualization and movement video. This issue can be quickly resolved by providing more clear instructions or designing a new survey interface that allows participants to watch both videos in the same window (Fig. 6.8).

Figure 6.8. Original survey format (left) and suggested survey format (right)
Chapter 7.

Comparative Analysis

To bring high-level analysis and discussion to the EMVIZ systems evaluation, this chapter describes the unit of analysis, levels of analysis, and comparative analysis procedures used to criticize, analyze, and compare the design strategies of three EMVIZ visualization systems. Usability testing results from the previous chapter are incorporated and used to support the comparative analysis process. To reveal the best set of design criteria for communicating expressive movement qualities, the comparative analysis evaluates the strengths and weaknesses of three design strategies for visualizing movement quality and describes why these design strategies could or could not generate the visualizations they are intended to represent. The analysis procedure is separated into three parts: (1) defining the unit and level of analysis; (2) criticizing, analyzing, and comparing each Basic-Effort-Action among systems; and (3) establishing a set of design criteria for communicating expressive movement qualities.

First, the communicative ability of the eight Basic-Effort-Actions visualization and their Effort factors (i.e., Space, Weight, and Time) were defined as the units of observation or the units of analysis. To define the levels of analysis, Jacques Bertin’s visual variables concept and affective motion textures experiment variables (see section 7.1) were incorporated to define eight visual variables (i.e., shape, direction, motion path curvature, texture, size, colour, speed, and acceleration) in association with three Effort factors: Space, Weight, and Time. These visual variables were defined as eight levels of analysis and they were used to critique, analyze, and compare the effectiveness of the design strategies and output visualizations of the three EMVIZ systems.

Second, the procedure of criticizing, analyzing, and comparing the three EMVIZ systems was divided into four steps:
• Reviewing output visualizations from three EMVIZ systems (i.e., eight Basic-Effort-Actions per system) and decoupling each Basic-Effort-Action visualization’s visual structure and associating it with eight levels of analysis;

• Arranging the eight levels of analysis of each Basic-Effort-Action visualization into a table in order to compare the three EMVIZ systems;

• Criticizing, analyzing, and comparing the strengths and weaknesses of each Basic-Effort-Action visualization and describing how and why it is or is not effective; and

• Using usability testing results and participant feedback to support claims and arguments.

Third, the final step was to summarize and establish the design criteria for visualizing eight movement qualities (i.e., Press, Glide, Punch, Dab, Wring, Float, Slash, and Flick). To illustrate the application of the design criteria, three examples and design criteria limitations are presented (see section 7.5).

7.1. Unit of Analysis and Levels of Analysis

In the EMVIZ systems design process, the creative use and poetics of metaphoric mappings across modalities from human movement to visualization was explored. This resulted in three different design strategies described in Chapter 4. Each EMVIZ design strategy was composed of a set of design rules and colour palettes derived from visual communication and visual art theories, and computation was used as a technique for representing movement quality.

To perform a deep analysis on each design strategy, Jacques Bertin’s visual variables concept was used to define the levels of analysis in association with Effort factors for each EMVIZ system. Jacques Bertin is a French cartographer and theorist who laid the foundation of visualization practice, human perception theory, graphic and quantitative data representation, and guidelines for creating effective data visualization (Bertin, 1983). In his book *Semiology of Graphics*, Bertin described the characteristics of
seven visual variables (i.e., position, size, shape, value, colour, orientation, and texture) and identified which visual variable would be most appropriate to represent each aspect of the information in cartography. Position refers to the change of x and y location in the space. Size is the change of width and height of shape or area in the space. Shape is the area that defines an object in space. Value refers to the change from light to dark. Colour is the change of hue at a given value. Orientation is the change of alignment of shape in the space. Texture is the change of surface quality. However, these variables were described mainly based on cartography or two-dimensional print materials. In the information visualization field, Bertin’s concept was further explored and discussed as to how the seven visual variables could be used to represent information in information visualization research¹ (Carpendale, 2001).

In information visualization research, motion is an important variable that needs to be taken into account in relation to the visual variable for computational generated visualization. Motion has been extensively researched in terms of what motion attributes convey meaningful information or are effective for information visualization tasks (Amaya et al., 1996; Bartram and Ware, 2002; Huber and Healey, 2005) and what attributes communicate affect (Bartram and Nakatani, 2010; Feng, 2014; Lockyer and Bartram, 2012; Lockyer et al., 2011; Nakatani, 2009). These researchers presented empirical evidence of how motion properties (e.g., direction, path curvature, texture shape, and speed) contribute to affective impressions and they reported that even simple variations of these motion properties can influence affective impressions.² For instance, fast and angular motions are perceived as negative, urgent, exciting, and threatening, while straight motions are more positive, reassuring, and relaxed.

To find similarities between human motion and computer-generated motion, I metaphorically compared motion properties defined in affective motion research and Bertin’s visual variables concept with LMA Effort factors and found that they share the same properties across the modalities, such as direction, trajectory or speed. For instance, Weight Effort shares similar properties with size and colour visual variables. Changing the object’s size, colour values or colour saturation can convey a sense of

¹ See: Carpendale, M.S.T. Considering Visual Variables as a Basis for Information Visualisation, University of Calgary, Department of Computer Science, 2001-693-16, 2003.
² See: Feng, 2014; Lockyer et.al 2011; Lockyer and Bartram, 2012
Strength or Lightness according to visual perception theory and colour psychology (Arnheim, 2004). Space Effort shares similar properties with motion properties such as direction or motion trajectory, while Time Effort shares the same properties with motion properties such as speed or acceleration. Thus, I incorporated motion properties from affective motion research with Bertin’s visual variables concept and defined the eight visual variables in association with three Effort factors: Space, Weight, and Time. Table 7.1 presents the eight visual variables as the levels of analysis used in the comparative analysis.

Table 7.1. Eight levels of analysis used in comparative analysis process

<table>
<thead>
<tr>
<th>Effort Factors</th>
<th>Visual Variables</th>
<th>Values</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SPACE</strong></td>
<td>Shape (Single)</td>
<td>Point, Line, Plane (Geometric or Abstract)</td>
<td>![Shape Examples]</td>
</tr>
<tr>
<td></td>
<td>Shape (Overall)</td>
<td>Linear, Radial, Spherical, Spiral or Abstract</td>
<td>![Shape Examples]</td>
</tr>
<tr>
<td></td>
<td>Texture</td>
<td>With Texture, Without Texture</td>
<td>![Texture Examples]</td>
</tr>
<tr>
<td></td>
<td>Direction</td>
<td>Left, Right, Upward, Downward, Upward-Left, Upward-Right, Downward-Left, Downward-Right, Toward or Outward from Centre</td>
<td>![Direction Examples]</td>
</tr>
<tr>
<td></td>
<td>Motion Path</td>
<td>Straight, Curve, Angular, Meandering, or All (random)</td>
<td>![Motion Path Examples]</td>
</tr>
<tr>
<td></td>
<td>Curvature</td>
<td>![Curvature Examples]</td>
<td></td>
</tr>
<tr>
<td><strong>WEIGHT</strong></td>
<td>Size</td>
<td>Increase, Decrease</td>
<td>![Size Examples]</td>
</tr>
<tr>
<td></td>
<td>Colour</td>
<td>[Hue, Saturation, Value]: Fix, Increase, Decrease</td>
<td>![Colour Examples]</td>
</tr>
<tr>
<td><strong>TIME</strong></td>
<td>Speed</td>
<td>Fast, Slow</td>
<td>![Speed Examples]</td>
</tr>
<tr>
<td></td>
<td>Acceleration</td>
<td>Increase, Decrease</td>
<td>![Acceleration Examples]</td>
</tr>
</tbody>
</table>

Note. See the description and discussion of eight visual variables used in this comparative analysis in Appendix D, section 1.
7.2. Criticizing, Analyzing, and Comparing Three EMVIZ Systems

The comparative analysis is separated into two main parts: (1) holistic analysis of the three EMVIZ systems and (2) microanalysis of each Basic-Effort-Action visualization across the three EMVIZ systems. Holistic analysis compares the three EMVIZ systems as a whole, while microanalysis details the comparison of each Basic-Effort-Action visualization (i.e., Press, Glide, Punch, Dab, Wring, Float, Slash, and Flick) across the three EMVIZ systems. Figure 7.1 presents the analysis structure described in this section.

![Comparative Analysis Diagram]

**Figure 7.1. The structure of comparative analysis**

In each section, each Basic-Effort-Action visualization’s structure was reviewed, decoupled, and associated with the eight levels of analysis, in order to perform deep analysis of the three EMVIZ systems’ design features. All information was arranged in a
Table in order to make the comparison; for instance, Table 7.2 presents the analysis table for the EMVIZ (Motion-Agent) Punch visualization.

Table 7.2. The analysis table for EMVIZ (Motion-Agent) Punch visualization

<table>
<thead>
<tr>
<th>Effort Factors</th>
<th>SPACE</th>
<th>WEIGHT</th>
<th>TIME</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Shape (Single)</td>
<td>Shape (Overall)</td>
<td>Texture</td>
</tr>
<tr>
<td>Rectangle (fill)</td>
<td>Resemble spiral and abstract shape</td>
<td>With Texture</td>
<td>Burst out from centre and quickly move toward centre</td>
</tr>
</tbody>
</table>

Note. All information derived from Punch visualization observation. H = hue, S = saturation, and V = value.

The following sections present the analysis of overall visualization and the eight Basic-Effort-Actions visualizations across three EMVIZ systems. The holistic analysis section summarizes the three Effort factors analysis (Space, Weight, Time) for three EMVIZ systems. In this process, each section begins with the comparative analysis table, followed by the strengths and weakness of each system supported by usability testing results.

7.3. Holistic Analysis of Three EMVIZ Systems

First, all visualizations generated by the three EMVIZ systems were observed in order to analyze each EMVIZ system’s design features (See Appendix D, section 2). Each visualization’s design feature was decoupled, associated with the eight levels of analysis, and arranged in a table in order to make the comparison. Figure 7.2 presents the resulting comparative analysis table for the three EMVIZ systems.

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\(^3\) The comparative analysis table derives from the process of observing output visualization and arranging all observed information into a table. This process is used for comparing pre-defined design strategies of three EMVIZ systems described in Chapter 4 with the final output visualization generated by three EMVIZ systems.
### Figure 7.2. The comparative analysis of three EMVIZ systems: EMVIZ (Motion-Agent), EMVIZ (Sketch), EMVIZ (L)

Note: See a brief summary of similarities and differences of three EMVIZ systems in Appendix D, section 3.
The analysis table illustrates some similarities and differences among three mapping design strategies. To find each EMVIZ system’s communication problems, the three mapping design strategies defined in Chapter 4 were compared with the eight levels of analysis table (Figure 7.2) in order to identify any problems in applying design strategy to computation. The following sections describe identified problems as well as the strengths and weaknesses of the three EMVIZ systems based on three Effort factors.

7.3.1. SPACE

The comparison between the mapping design strategy and the eight levels of analysis table (Figure 7.2) demonstrated that the Space Effort design strategy of system A and B (defined in Chapter 4) differs from the analysis table results (i.e., direction and motion path curvature). For instance, the system A Punch mapping design strategy was originally intended to create a “randomly moving toward centre” motion pattern but the output visualization was “burst out from centre and moving toward centre” motion pattern. This difference indicates that there were some problems in applying mapping design strategy to computation or visual generation process.

7.3.1.1. System A: EMVIZ (Motion-Agent)

For system A, this problem occurred because of the computation used for generating visualization (i.e., boids system or flocking algorithm). Two explanations for the Space Effort problems are described as follows:

- First, in flocking simulations (i.e., computation used for generating visualization), there is no central control because each agent moves or behaves autonomously. In other words, each agent has to configure its own movement according to other agents' movements. This process may result in emergent behaviour - in this case, unanticipated behaviour shown by all agents' movement. For instance, when a stream of data from EffortDetect was mapped to the pre-set parameters defined for Punch visualization, the flocking agents (i.e., the random moving shapes) changed their behaviour from random motion to a specific motion quality (i.e., Punch). In this transition from one motion quality to another, each agent adjusts itself and interacts with

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4 Emergent behavior is the global (systematic) consequence of local interactions of individuals in the system’s population, such as bird flocks, that exhibit unique natural and dynamic patterns that behave in unexpected ways that are not predictable from the behavior of their members (Graham, 2013), see: http://www.patternsinnature.org/Book/EmergentPatterns.html.
other agents according to the changes in parameter values, resulting in a pattern of bursting out from the centre and moving toward centre (i.e., unanticipated behaviour or undesired motion pattern) instead of randomly moving toward centre. Thus, the main issue is unpredictable motion pattern caused by the nature of computation used for generating visualization.

- Second, straight and curve motion path curvatures were generated by unpredictable motion patterns which (1) created a sense of Direct Effort and Indirect Effort at the same time and (2) made the overall shape of visualization looked more abstract than intended.

These two major problems can decrease the ability to communicate Space Effort. These assumptions are supported by usability testing results (Chapter 6), reflected by a low percentage of correctly identified Space Effort parameter (i.e., 44.8% [Direct 37.5% and Indirect 52%]; see Appendix C, section 2.3.7). Participants also reported that Space Effort seemed confusing and difficult to identify because (1) they were confused about which part of the visualization to focus on and (2) some visualizations contained two Effort parameter values (e.g., Direct and Indirect). Thus, identifying the eight Basic-Effort-Actions in the visualization sequence is dependent upon which part of the visualization to focus on. These two issues are (1) multiple foci in visualization and (2) multiple Effort parameter values presented in the visualization, respectively.

7.3.1.2. System B: EMVIZ (Sketch)

System B has a similar problem to system A (i.e., the differences between pre-defined design strategy and the result of eight levels of analysis in Figure 7.2). However, there were only slight differences between the pre-defined design strategy and the output visualizations (i.e., direction and motion path curvature). Thus, visualizations were correctly generated almost exactly as described in the pre-defined design strategy, except for Wring visualization. For Wring visualization, a pre-defined design strategy was intended to generate “moving toward centre” motion within a spiral and concentric visual structure. However, the output visualization resulted in “moving from all directions toward centre and moving outward from centre to all directions” with meandering and straight path curvature. This made the overall shape of the visualization look and feel like a radial shape (i.e., conveyed a sense of Direct Effort) instead of a spiral shape (i.e., conveyed a sense of Indirect Effort). This problem occurred because the design strategy was not well-implemented in computation (i.e., programming or coding process). Thus, it possibly led to incorrect Basic-Effort-Actions visualization identification because some
people might interpret Wring visualization (Indirect, Strong, and Sustained) as Press visualization (Direct, Strong, and Sustained).

These assumptions are supported by the low percentage of correctly identified Wring visualization and Space Effort (i.e., 16.7% [Direct 58.3% and Indirect 16.7%]; see Appendix C, section 2.3.7). More than half of the participants identified Direct Effort instead of Indirect Effort. However, all visualizations also had a low percentage of correctly identified Space Effort parameter (i.e., 39.6% [Direct 31.3% and Indirect 47.9%]), although most visualizations were generated correctly as described in the pre-defined design strategy. This means either the design strategy failed to communicate Space Effort or it was not well implemented in computation during the system implementation process. My assumption is that design strategy was not the problem because it was defined based on visual perception theory (e.g., Rudolph Arnheim art and visual perception or gestalt theory of perception\(^5\)). I believe that the problem is that the design strategy was not well implemented in computation (i.e., programming or coding process).

7.3.1.3. **System C: EMVIZ (L)**

System C’s problem is similar to system A in terms of unpredictable motion patterns caused by the nature of computation used for generating visualizations. This is because system C used L-system algorithm, which generates less predictable or highly disordered outcomes,\(^6\) resulting in less control of output visualization. This issue can cause Space Effort communication issues because of uncontrollable motion direction. All visualizations were randomly generated from the centre of the screen and motion direction could not be controlled or pre-defined in the design strategy. This resulted in straight and angular motion path curvature, which conveyed a sense of Direct Effort or Indirect Effort at the same time. For overall look and feel, Space Effort was very hard to identify because of the visual complexity generated by the L-system algorithm.

These assumptions were confirmed by a low percentage of correctly identified Space Effort parameter (i.e., 20.9% [Direct 12.5% and Indirect 29.2%]; see Appendix C,

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section 2.3.7). These results demonstrate that system C failed to communicate Space Effort. Participants also reported that they could not identify Space Effort and they guessed on the overall quality of the visualization. Approximately 40% of participants could not identify Space Effort (i.e., chose neither Direct and Indirect in task 2 of the questionnaire). Table 7.3 summarizes and compares the strengths and weaknesses of Space Effort communication among the three EMVIZ systems.

Table 7.3. The strengths and weaknesses of Space Effort communication among three EMVIZ systems

<table>
<thead>
<tr>
<th>Systems</th>
<th>Strengths</th>
<th>Weakness</th>
</tr>
</thead>
</table>
| A       | • Visualization or motion pattern never look the same every time they are generated.  
• The visual appearance of all visualizations has a sense of oneness (i.e., design unity).  
• Visualization looks natural, simple, modern, and smooth because of mapped texture.  
• The animation or motion of the visualization looks natural because they were simulated based on flocking behavior of birds. | • The transition between two motion patterns generates undesired motion properties caused by boids system.  
• Undesired motion pattern cause the overall shape of visualization to look more abstract than intended.  
• Visualization motions are less predictable (i.e., direction and motion path curvature).  
• Some visualizations contain more than one Effort parameter values (i.e., Direct and Indirect).  
• There are multiple foci in visualization making some participants unsure which part of motion or visualization to focus on in order to identify the eight Basic-Effort-Actions. |
| B       | • Visual appearance or motion pattern looks simple, making visualization easy to perceive.  
• Using different computation for each visualization gives more control of visual generation process because each visualization has its’ own parameters that can be precisely programmed. | • The visual appearance of all visualizations has no sense of oneness (i.e., design unity) because the Basic-Effort-Actions visualizations look different from each other.  
• Pre-design strategies were not well implemented in computation, resulting in Space Effort parameter values that were not clearly communicated.  
• Some visualizations contain more than one Effort parameter values (i.e., Direct and Indirect). |
| C       | • Visual appearance or motion patterns never look the same every time they are generated.  
• The visual appearance of all visualization has a sense of oneness (i.e., design unity). | • The overall abstractness of visualization has a strong effect on Space Effort perception.  
• Visualization motions are not predictable (i.e., direction and motion path curvature). |
7.3.2. WEIGHT

7.3.2.1. System A and B: EMVIZ (Motion-Agent) and EMVIZ (Sketch)

In the mapping design process, the size of the shape and colour code assigned for each Basic-Effort-Action were originally designed to enhance and support Weight Effort parameter values identification. Systems A and B Weight Effort design strategies (defined in Chapter 4) look the same as the result of the eight levels of analysis table presented in Figure 7.2 (i.e., using a specific colour code for each Basic-Effort-Action visualization and changing the size of the shape and colour saturation). Thus, there is no problem similar to the Space Effort problem identified in the previous section. However, there may be two primary issues regarding Weight Effort representation:

• The subjectivity of colour or cross-cultural colour perception regarding the colour code assigned to each Basic-Effort-Action visualization. For instance, green or light green was used to represent Float quality (Indirect, Light, and Sustained) but some people do not believe that these are the best colours for representing Float quality.

• Unclear visual transition among eight Basic-Effort-Actions visualizations. For instance, some people did not clearly see the changing of the size of the shape and colour saturation because of the abstractness of overall visualization.

These two problems can decrease the ability to communicate Weight Effort. These assumptions were supported by a low average percentage of correctly identified systems A and B Weight Effort parameters (i.e., system A = 46.9% [Strong 43.7% and Light 50%] and system B = 59.4% [Strong 50% and Light 68.8%]; see Appendix C, section 2.3.7, 2.38).

Another explanation is that the majority of participants did not pay attention to colour or did not identify the eight Basic-Effort-Actions based on visual and colour transition (i.e., changing of the size of the shape and colour saturation). They were focused mainly on the motion of the visualization. Some participants mentioned that colour sometimes subconsciously influenced Weight Effort identification but that sometimes it seemed confusing and difficult to use as a reference for identifying Weight Effort. This is because different people may have different opinions about colour in association to the eight Basic-Effort-Actions.
We cannot conclude that the colour code design strategy failed to communicate Weight Effort because there is no explicit evidence. However, we can make assumptions about colour communication based on which Basic-Effort-Action visualizations among systems are the best for representing Weight Effort according to inferential statistic analysis (see Chapter 6, Table 6.10). For instance, system B’s Weight Effort of Dab and Slash visualizations was significantly different and performed better than systems A and C.

7.3.2.2. System C: EMVIZ (L)

For system C, a pre-designed strategy of Weight Effort was identical to Figure 7.2’s results. System C’s colour design strategy differed from systems A and B in that six colour palettes were assigned to six Effort parameter values (i.e., Direct, Indirect, Strong, Light, Sudden, and Sustained) with fixed colour properties (i.e., hue, saturation, and value). Thus, each system C Basic-Effort-Action visualization was composed of three colour palettes. For instance, Punch visualization’s colour is composed of Direct, Strong, and Sudden colour palettes. This design strategy may have some problems regarding Weight Effort representation:

- First, some people cannot identify colour because there are more than one colour assigned to each Basic-Effort-Actions visualization. For instance, Punch visualization colour was a mix of red, orange, blue, and green.

- Colour was assigned fixed properties (i.e., hue, saturation, and value) and colour saturation did not change according to the values of a stream of Basic-Effort-Actions vectors data. Thus, Weight Effort can be identified only through the change of stroke weight and line length.

Thus, system C’s Weight is probably hard to identify because (1) each Basic-Effort-Action visualization contained more than one colour; (2) colour saturation was assigned fixed properties; and (3) overall visualization looked complex and abstract. These assumptions were confirmed by a very low percentage of correctly identified Weight Effort parameter (i.e., 34.4% [Strong 35.4% and Light 33.3%]; see Appendix C, section 2.3.7).

Table 7.4 summarizes and compares strengths and weaknesses of Space Effort communication among three EMVIZ systems.
### Table 7.4. The strengths and weaknesses of Weight Effort communication among three EMVIZ systems

<table>
<thead>
<tr>
<th>Systems</th>
<th>WEIGHT</th>
<th>Strengths</th>
<th>Weakness</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td></td>
<td>• Some colours influence Weight Effort identification subconsciously.</td>
<td>• Some participants did not pay attention to colour or did not use colour as a reference for identifying Weight Effort.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Size of the shape and colour saturation sometimes help identify Weight Effort.</td>
<td>• The transition of visual properties (i.e., change of the size of the shape and colour saturation) not able to clearly convey a sense of Weight Effort.</td>
</tr>
<tr>
<td>B</td>
<td></td>
<td>-</td>
<td>• The overall abstractness of visualization has a strong effect on Weight Effort perception.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Colour sometimes has a negative influence on Weight Effort identification because of the subjectivity of colour or cross-cultural colour perception.</td>
</tr>
<tr>
<td>C</td>
<td></td>
<td></td>
<td>• Colour cannot be clearly identified because there are multiple colours assigned to each Basic-Effort-Action visualization.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Colour was assigned fixed properties (i.e., hue, saturation, and value).</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• The transition of visual properties (i.e., line length and stroke weight) was not able to clearly convey a sense of Weight Effort.</td>
</tr>
</tbody>
</table>

#### 7.3.3. TIME

#### 7.3.3.1. System A: EMVIZ (Motion-Agent)

The comparison between mapping design strategy and the eight levels of analysis demonstrated that the Time Effort design strategies of systems A, B, and C were generated correctly as planned. However, there are two identified problems for system A:

- First, Flow Effort\(^7\) appeared in each sequence of Basic-Effort-Actions visualization. Flow Effort was not supposed to be present in the visualization because it was excluded in the eight Basic Effort Actions. However, Flow could be noticed because the visualization was generated in a continuous sequence due to the flocking algorithm. Thus, all visualization had a sense of continuity when motion properties of visualization changed from one visual pattern to another. This transition between two motion properties contains Flow Effort. This problem may have confused the movement experts (i.e., participants of this study) and made them unable to identify the Basic-Effort-Actions and their Effort factors (Space, Weight, and Time) because they

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\(^7\)Flow Effort refers to the continuity of movement. Flow was excluded or minimized in the Eight Basic-Effort-Actions theory because there is no continuity of movement in the eight Basic-Effort-Actions, see: Laban & Lawrence 1974.
noticed Flow Effort, which is not supposed to appear in the eight Basic-Effort-Actions. For instance, in Punch visualization, a random motion makes the transition to Direct, Strong, and Sudden motion pattern, and then changes back to a random motion pattern. Thus some participants may not have known which parts of the visualization to focus on in order to identify the Basic-Effort-Actions and associated Effort factors.

• Second, some visualizations contained more than one Effort parameter value. For instance, in the Press visualization, a group of particles quickly moves from all directions towards the centre and slowly dissipates outward from the centre. Thus the beginning of the motion is Sudden Time Effort (i.e., quickly moves from all directions towards the centre) but the middle and end of the motion is Sustained Time Effort (i.e., slowly dissipates outward from the centre). The problem lies in the transition from one motion pattern to another. In this case, when EffortDetect (i.e., a sensor) detects Press motion, the motion properties change from a random motion pattern to the Press motion pattern. In this transition, an undesired motion pattern appears (i.e., quickly moves from all direction toward centre). This issue is caused by the nature of flocking algorithm used for generating visualization, described in section 7.4.1.1.

These two problems can reduce the ability to communicate Time Effort. These assumptions were supported by two issues reported by participants, (1) multiple foci in visualization and (2) multiple Effort parameter values presented in the visualization (see Chapter 6, section 6.4.1). Although there were some communication problems, the average percentage of correctly identified Time Effort remained high (i.e., 88.6% [Sudden 91.7% and Sustained 85.5%]; see Appendix C, section 2.3.7). This is probably because Time Effort is the most salient motion feature that humans are able to perceive easily. However, if these two problems are fixed properly, Time Effort communication will be improved.

7.3.3.2. System B: EMVIZ (Sketch)

There may be two problems for system B regarding Time Effort communication:

• First, as with system A, some visualizations contained more than one Effort parameter value. For instance, Wring visualization contained both Sudden and Sustained Time Effort (i.e., the beginning and middle of the visualization are Sustained Time, and the visualization’s end is Sudden Time).

• Second, some visualizations conveyed a sense of fast or slow speed rather than Sudden and Sustained Time. This is probably because half of the system B visualizations used fixed speed with no acceleration (i.e., Punch, Dab, Glide, and Float visualizations [see Figure 7.2]). Some visualizations likely work well with this design strategy but some will not. This is because, in the real world, speed and acceleration are fundamental properties of movement. Thus, using only fixed speed makes the motion look less natural. This problem can make
some participants unable to identify Time Effort because they could not get a sense of Sudden Time or Sustained Time in the visualization.

These assumptions were confirmed by the usability testing results, which indicated approximately 33.3% incorrectly identified Time Effort. For instance, in Dab visualization, the percentage of correctly identified Sudden Time Effort was 66.7%. Two participants chose Sustained instead of Sudden Time and two participants chose neither Sudden nor Sustained Time. There were similar results for Wring and Float visualizations [see Appendix C, section 2.3.8]). Although Time Effort is the most salient motion feature that humans can easily perceive, these two problems made the average percentage of correctly identified Time Effort parameter for system B lower than predicted (74% [Sudden 81.3% and Sustained 66.7%]; see Appendix C, section 2.3.7). Participants also reported that Time Effort was difficult to identify because some visualizations contained two Effort parameter values (e.g., Sudden and Sustained). This issue is called multiple Effort parameter values presented in the visualization (see Chapter 6, section 6.4.1).

7.3.3.3. **System C: EMVIZ (L)**

An issue identified for system C is the overall quickness of all visualizations. System C used fixed speed without acceleration parameter value, causing the animation speed of visualization to look less natural than other EVMIZ systems. The visualization might convey a sense of fast or slow speed rather than Sudden and Sustained Time (i.e., similarly to system B’s problem). There are two explanations for Time Effort problems, as follows:

- First, Stochastic L-system\(^8\) does not need an acceleration parameter as a function of time for generating visualization, but a speed parameter is required in order to define the speed of the animation (i.e., speed of the visualization).
- Second, EMVIZ (L) has a computation issue because the system runs so slowly when generating the visualization. This problem can be explained by the fact that the EMVIZ (L) used L-system software library,\(^9\) which was not

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\(^8\) Stochastic L-system is a technique or computation used for generating visualization. See: Chapter 4, section 4.4.1.2.

\(^9\) L-system library is an open source Java Processing Library developed by Martin Prout.
designed to support the process of producing a long sequence of strings according to the design rules defined in design strategy (see Chapter 4, section 4.4.1.2). Thus there might be some functions in the program that slow down system performance when the system generates visualizations.

However, this proposed explanation was not confirmed by the usability testing results because the average percentage of correctly identified Time Effort parameter was still good (i.e., 71.9% [Sudden 85.4% and Sustained 58.3%]; see Appendix C, section 2.3.9). However, I observed in all visualizations that quick motion was too quick while Sustained motion sometimes looked faster than intended. Some participants reported that they were confused because of the abstractness and overall quickness of the visualization. Therefore they guessed their Time Effort identification through the quickness or slowness of the animation rather than through observing motion qualities (see Chapter 6, section 6.4.3).

Although the average percentage of correctly identified Time Effort (71.9%) and Sudden Time (85.4%) were high, the percentage of correctly identified Sustained Time was low (58.3%). This is because, in task 2 of the questionnaire (i.e., Effort identification), around 30 - 40% of participants could not identify Time Effort. Some participants incorrectly identified Time Effort (i.e., Sudden instead of Sustained) and some chose neither Sudden nor Sustained instead of Sustained Time (see Appendix C, section 2.3.9). Table 7.5 summarizes and compares the strengths and weaknesses of Time Effort communication among three EMVIZ systems.

L-system is a string rewriting system that defines complex objects by successively replacing parts of a simple initial object using a set of rewritten rules or productions (Prusinkiewicz et al. 1990; Whitelaw 2004). L-system interprets a string of characters as a linear sequence of instructions, generating graphics with an organic aesthetic (Prusinkiewicz et al. 1990).
<table>
<thead>
<tr>
<th>Systems</th>
<th>Strengths</th>
<th>Weaknesses</th>
</tr>
</thead>
</table>
| **A** | • Animation speed of all visualizations looks natural. | • Flow Effort can be recognized in all visualizations, causing multiple foci in visualization and some confusion in identifying Effort parameter values.  
• There are multiple foci in visualization, causing some participants to be unsure which part of motion or visualization to focus on.  
• Some visualizations contain more than one Effort parameter value (i.e., Sudden and Sustained). |
| **B** | • The animation speed of some visualizations looks natural. | • The animation speed of some visualizations looks less natural (i.e., conveying a sense of fast or slow speed rather than Sudden and Sustained).  
• Some visualizations contain more than one Effort parameter value (i.e., Sudden and Sustained). |
| **C** | - | • Sudden motion is too quick while Sustained motion sometimes looks faster than intended.  
• Some functions in the system slow down system performance when the system produces complex visualization.  
• The animation speed of some visualizations looks less natural (i.e., conveying a sense of fast or slow speed rather than Sudden and Sustained). |
### 7.3.4. Summary

Table 7.6 summarizes the strengths and weaknesses of three EMVIZ systems.

#### Table 7.6. The strengths and weaknesses of three EMVIZ systems.

<table>
<thead>
<tr>
<th>Systems</th>
<th>Effort</th>
<th>Strengths</th>
<th>Weaknesses</th>
</tr>
</thead>
</table>
| **A**   | **SPACE** | • Visualization or motion pattern never look the same every time they are generated.  
• The visual appearance of all visualizations has a sense of oneness (i.e., design unity).  
• Visualization looks natural, simple, modern, and smooth because of mapped texture.  
• Motion patterns look natural because they were simulated based on flocking behavior of birds. | • The transition between two motion patterns generates undesired motion properties caused by boids system.  
• Undesired motion patterns make the visualization’s overall shape look more abstract than intended.  
• Visualization motions are less predictable (i.e., direction and motion path curvature).  
• Some visualizations contain more than one Effort parameter value (i.e., Direct and Indirect).  
• Multiple foci in visualization made some participants unsure which part of motion or visualization to focus on in order to identify the eight Basic-Effort-Actions. |
| **B**   | **SPACE** | • Visual appearance or motion patterns look simple, making visualization easy to perceive.  
• Using different computation for each visualization gives more control of visual generation process because each visualization has its own parameters that can be precisely programmed. | • Flow Effort can be recognized in all visualization, causing multiple foci in visualization.  
• Multiple foci in visualization made some participants unsure which part of motion or visualization to focus on.  
• Some visualizations contain more than one Effort parameter value (i.e., Sudden and Sustained). |

**WEIGHT**

<table>
<thead>
<tr>
<th>Effort</th>
<th>Strengths</th>
<th>Weaknesses</th>
</tr>
</thead>
</table>
| • Some colours influence Weight Effort identification subconsciously.  
• Size of the shape and colour saturation sometime help identify Weight Effort. | • Some participants did not pay attention to colour or use colour as a reference to identify Weight Effort.  
• The transition of visual properties (i.e., change of the size of the shape and colour saturation) was unable to clearly convey a sense of Weight Effort.  
• The overall abstractness of visualization has a strong effect on Weight Effort perception.  
• Colour sometimes has a negative influence on Weight Effort identification because of the subjectivity of colour or cross-cultural colour perception. |

**TIME**

<table>
<thead>
<tr>
<th>Effort</th>
<th>Strengths</th>
<th>Weaknesses</th>
</tr>
</thead>
</table>
| • Animation speed of the visualization looks natural. | • Flow Effort can be recognized in all visualization, causing multiple foci in visualization.  
• Multiple foci in visualization made some participants unsure which part of motion or visualization to focus on.  
• Some visualizations contain more than one Effort parameter value (i.e., Sudden and Sustained). |

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| WEIGHT | • Some colours influence Weight Effort identification subconsciously.  
• Size of the shape and colour saturation sometime help identify Weight Effort.  
• Some participants did not pay attention to colour or did not use colour as a reference to identify Weight Effort.  
• The transition of visual properties (i.e., the changing of the size of the shape and colour saturation) was unable to clearly convey a sense of Weight Effort.  
• The overall abstractness of visualization has a strong effect on Weight Effort perception.  
• Colour sometimes has a negative influence on Weight Effort identification because of the subjectivity of colour or cross-cultural colour perception. |
| TIME | • Animation speeds of some visualizations look less natural (i.e., conveying a sense of fast or slow speed rather than Sudden and Sustained Time).  
• Some visualizations contain more than one Effort parameter value (i.e., Sudden and Sustained). |
| SPACE | • Visual appearance or motion patterns never look the same every time they are generated.  
• The visual appearance of all visualization has a sense of oneness (i.e., design unity).  
• The overall abstractness of visualization has a strong effect on Space Effort perception.  
• Visualization motions are not predictable (i.e., direction and motion path curvature). |
| WEIGHT | • Colour cannot be identified clearly because there are multiple colours assigned to each Basic-Effort-Action visualization.  
• Colour was assigned fixed properties (i.e., hue, saturation, and value).  
• The transition of visual properties was unable to clearly convey a sense of Weight Effort (i.e., line length and stroke weight). |
| TIME | • Sudden motion is too quick while Sustained motion sometimes looks faster than intended.  
• Some functions in the system slow down system performance when the system produces complex visualization.  
• Animation speed of some visualization look less natural (i.e., conveying a sense of fast or slow speed rather than Sudden and Sustained Time). |

### 7.4. Microanalysis of Three EMVIZ Systems

To identify their problems, strengths, and weaknesses, each Basic-Effort-Action visualization was analyzed, compared, and arranged in a table according to the eight levels of analysis (see Table 7.1). Similarly to holistic analysis, the analysis process begins with the comparative analysis table, communication problems, and supported
usability testing data, followed by a summary of the best design strategy for representing Basic-Effort-Actions visualization. The following sections present (1) a brief summary of microanalysis results for each Basic-Effort-Action visualization across three EMVIZ systems (see a descriptive analysis in Appendix D, section 4) and (2) design suggestions for improving visual communication of Effort parameter values.

7.4.1. Press Visualization

Three EMVIZ systems equally communicated three Effort parameters (Space, Weight, and Time) and Press quality. However, the EMVIZ (Motion-Agent) design strategy appeared to be the best for communicating Direct Space Effort if we eliminated unpredictable motion pattern (i.e., moving toward centre) that generates a curve motion path curvature. To improve Direct Space Effort communication, I propose:

• Using “moving outward from centre” motion direction and ensuring that motion path curvature of visualization is straight. This strategy not only makes Direct Space Effort easy to perceive but also eliminates a sense of Indirect Effort cause by curve motion path curvature.

• Ensuring that the overall shape of visualization does not look too abstract in order to create clear communication and avoid cognitive load.\(^{11}\) Making the overall shape of visualization resemble a radial shape is also recommended.

For Weight Effort communication, a purple colour scheme can be used as (1) some movement experts mentioned that purple seemed to have a Strong Weight quality and (2) there is no empirical evidence indicating that purple cannot convey a sense of Strength. To improve Weight Effort communication, I propose:

• Using a purple colour scheme with high colour intensity (i.e., saturation) and colour value (i.e., brightness) because the darker or more saturated a colour is, the more it connotes forcefulness (Wright & Rainwater 1962).

• Ensuring that increased colour saturation and the size of the shape correspond to Sustained Time Effort (i.e., slowly increasing).

\(^{11}\) In cognitive psychology, cognitive load refers to the state of being overwhelmed by information or mentally attending to one or more tasks peripheral to the task at hand, which can have the effect of reducing learning performance because one cannot completely concentrate on the target task, see: http://www.psychwiki.com/wiki/Cognitive_Load.
To improve Time Effort communication, we should ensure that the animation speed (i.e., Sustained motion) corresponds to slowly increasing size of the shape and colour saturation.

7.4.2. Glide

The EMVIZ (Motion-Agent) and EMVIZ (Sketch) design strategies are the best for communicating Direct Effort. To improve Direct Space Effort communication, I propose:

- Using “moving upward-right and right or upward-left or left” motion direction and ensuring that a motion path curvature of visualization is straight. This strategy makes Direct Space Effort easy to perceive and eliminates a sense of Indirect Effort (i.e., multiple foci in the visualization) caused by curve motion path curvature.
- Ensuring that the overall shape of visualization looks linear instead of abstract.

For Weight Effort communication, a light blue or aqua blue colour scheme can be used to represent Light Weight Effort because they are considered cool colours and colour psychology theory suggests that “the more hue a colour has, the more it connotes calmness” (Wright & Rainwater 1962). To improve Weight Effort, I propose:

- Using a light blue or aqua blue colour scheme with medium colour intensity and high colour value. This colour setting will create a sense of Lightness.
- Ensuring that slowly increasing colour saturation and the size of the shape correspond to Sustained Time Effort.

EMVIZ (Motion-Agent) and EMVIZ (Sketch) design strategies are the best for communicating Sustained Time Effort. To improve Time Effort, we should ensure that animation speed (i.e., Sustained motion) corresponds to slowly increasing size of the shape and colour saturation.

7.4.3. Punch

In regards to Punch, EMVIZ (Sketch) performed better than EMVIZ (Motion-Agent). EMVIZ (Sketch) and EMVIZ (L), on the other hand, equally communicated Punch quality, as did EMVIZ (Motion-Agent) and EMVIZ (L). Additionally, EMVIZ
(Sketch) and EMVIZ (L) equally communicated Space Effort. To improve Direct Space Effort communication, I propose:

- Using either “bursting out from the centre or moving towards the centre” motion direction and ensuring that motion path curvature is straight.
- Ensuring that the overall shape of visualization does not appear too abstract. I also recommend making the overall shape of visualization resemble either radial or spherical shapes. This design strategy will make Direct Space Effort easy to perceive through a straight motion path curvature.

For Weight Effort communication, the three EMVIZ systems equally communicated Strong Weight Effort. A red colour scheme can be used to represent Strong Weight Effort because red is considered a warm colour and colour psychology theory suggest that “the darker or more saturated a colour is, the more it connotes forcefulness” (Wright & Rainwater 1962). Additionally, participants also reported that “red colour is helpful in indicating strength (ID 35)” or “I associate certain colo[u]rs with more strength” and “Red looked Stronger (ID 43).” To improve Weight Effort, I propose

- Using a red or red-orange colour scheme with high colour intensity and colour value. This will help convey a sense of Strong Effort.
- Ensuring that quickly increasing colour saturation and the size of the shape correspond to Sudden Time Effort.

For Time Effort, the three EMVIZ systems equally communicated Sudden Time Effort. To improve Time Effort, we should ensure that animation speed corresponds to quickly increasing size of the shape and colour saturation.

### 7.4.4. Dab

The three EMVIZ systems equally communicated Dab quality, but three Effort parameters (Space, Weight, and Time) were not equally communicated. For Space Effort, EMVIZ (Motion-Agent) performed better than EMVIZ (Sketch) and EMVIZ (L). Thus the EMVIZ (Motion-Agent) design strategy is the best for communicating Direct Space Effort and it could be further improved by eliminating the “moving toward centre” motion (i.e., unpredictability of motion patterns) and curve motion path curvature. To improve Direct Space Effort communication, I propose:

- Using either “moving towards the centre” or “moving outwards from centre” motion direction with a straight motion path curvature.
• Ensuring that the overall shape of visualization resembles a spherical shape.

For Weight Effort communication, the EMVIZ (Sketch) design strategy is the best for communicating Light Weight Effort and can be further improved if the changing visual properties (i.e., size, stroke weight or colour saturation) and the lightness of colour (i.e., magenta) are clearly represented. To improve Light Weight Effort communication, I propose:

• Using a red-purple colour scheme with low colour intensity but high colour value in order to create a sense of Light Effort.
• Ensuring that quickly increasing size of the shape and colour saturation (just a little) corresponds to Sudden Time Effort.

The EMVIZ (Motion-Agent) and EMVIZ (L) design strategies are the best for communicating Sudden Time Effort. However, they could be improved by ensuring the animation speed corresponds to quickly increasing size of the shape and colour saturation.

7.4.5. Wring

The EMVIZ (Motion-Agent) and EMVIZ (L) design strategies are the best for communicating Indirect Space Effort if (1) the “moving outwards from centre” direction is eliminated and (2) the motion path curvature meandered and curved instead of straightening. To improve Direct Space Effort communication, I propose:

• Using “moving from all directions toward centre” spiral motion direction with the curve or meander motion path curvature.
• Ensuring that the overall shape of visualization resembles spiral shape.

Weight Effort was equally communicated among all systems. A blue-purple colour scheme can be perceived as Strength and Lightness depending on colour intensity. The transition of object size and colour saturation was not well communicated. To improve Strong Weight Effort communication, I propose:

• Using a blue-purple colour scheme with medium colour intensity and colour value to create a sense of Strong Effort.
• Ensuring that slowly increasing size of the shape and decreasing colour saturation (just a little) corresponds to Sustained Time Effort.
The EMVIZ (Motion-Agent) system is the best for communicating Sustained Time Effort. However, it could be improved by ensuring the animation speed corresponds to slowly increasing size of the shape and colour saturation.

7.4.6. **Float**

The three EMVIZ systems equally communicated Space Effort and Press quality. To improve Indirect Space Effort communication, I propose:

- Using “moving upward, upward-left, and upward right” motion direction and ensuring that the motion path curvature is curved and meandering instead of straight.
- Ensuring that the overall shape of visualization looks simple and resembles a non-linear shape. This will make Indirect Space Effort easily perceived through the curve and meander motion path curvature.

Weight Effort was not equally communicated across systems and EMVIZ (Sketch) performed better than EMVIZ (L). EMVIZ (Motion-Agent) and EMVIZ (Sketch), on the other hand, equally communicated Light Weight Effort, as did EMVIZ (Motion-Agent) and EMVIZ (L), comparatively. To improve Light Weight Effort communication, I propose:

- Using a green, light-green or lime green colour scheme with medium colour intensity and high colour value to create a sense of Light Effort.
- Ensuring that slowly increasing the size of the shape (just a little) and decreasing colour saturation corresponds to Sustained Time Effort.

Time Effort was not equally communicated and the EMVIZ (Motion-Agent) design strategy is the best for communicating Sustained Time Effort. However, the strategy could be improved if the animation speed (i.e., Sustained motion) corresponds to slowly increasing the size of the shape and colour saturation.

7.4.7. **Slash**

The three EMVIZ systems did not equally communicate Slash quality. EMVIZ (Sketch) performed better than EMVIZ (Motion-Agent). EMVIZ (Sketch) and EMVIZ (L), on the other hand, equally communicated Slash quality, as did EMVIZ (Motion-Agent) and EMVIZ (L). However, the three EMVIZ systems equally communicated Space Effort. To improve Indirect Space Effort communication, I propose:
• Using a “randomly moving outwards from centre in all directions” motion direction and ensuring that the motion path curvature is angular and straight in order to convey a sense of multiple foci or Indirect Effort in the visualization.

• Ensuring that the overall shape of the visualization resembles an angular shape and is somewhat abstract. This will make Indirect Space Effort easily perceived through the angular and straight motion path curvature.

The three EMVIZ systems did not equally communicate Weight Effort. The EMVIZ (Sketch) design strategy is the best for communicating Strong Weight Effort because it performed better than systems EMVIZ (Motion-Agent) and EMVIZ (L). To improve Strong Weight Effort communication, I propose:

• Using an orange or orange-red colour scheme with high colour intensity and colour value to create a sense of strength.

• Ensuring that quickly increasing colour saturation and the size of the shape correspond to Sudden Time Effort.

The three EMVIZ systems equally communicated Time Effort. To improve Sudden Time Effort communication, we should ensure that animation speed (i.e., Sudden motion) corresponds to quickly increasing the size of the shape and colour saturation.

7.4.8. Flick

The three EMVIZ systems did not equally communicate Flick quality. EMVIZ (Sketch) performed better than EMVIZ (Motion-Agent). EMVIZ (Sketch) and EMVIZ (L), on the other hand, equally communicated Flick quality, as did EMVIZ (Motion-Agent) and EMVIZ (L) comparatively. However, the three EMVIZ systems equally communicated three Effort parameters (Space, Weight, and Time). To improve Space Effort design strategy, I propose:

• Creating, in the beginning of motion, a spiral or twist motion with fade in transition at the upward left or upward right position of the screen.

• Ensuring that a motion path curvature generated by a spiral or twist motion is curved.

• Using, in the middle to the end of motion, “moving outwards from centre to all directions” motion and ensuring that path curvature is straight.

• Ensuring that the overall shape of visualization is not too abstract and resembles a spiral shape in the beginning of visualization.
To improve Weight Effort communication, I propose:

- Using yellow-orange, yellow-green or light green colour schemes with medium colour intensity and high colour value.
- Ensuring that animation speed (i.e., Sudden motion) corresponds to quickly decreasing the size of the shape and increasing colour saturation.

To improve Time Effort, we should use accelerated motion in the beginning of a visualization sequence (i.e., spiral or twist motion) and Sustained motion (i.e., moving outwards from centre to all directions) for the rest of the visualization sequence.

7.4.9. Summary

Table 7.7 summarizes the design criteria for representing eight movement qualities.

Table 7.7. Design criteria for representing movement quality

<table>
<thead>
<tr>
<th>The eight BEAs</th>
<th>Design Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SPACE</strong></td>
<td><strong>WEIGHT</strong></td>
</tr>
<tr>
<td>Overall</td>
<td>• Use a simple geometrical shape and non-complex computation to generate visualization to avoid the overall abstractness of visualization.</td>
</tr>
<tr>
<td>Press</td>
<td>• Use “moving outwards from centre” motion direction, and ensure that a motion path curvature of visualization is straight.</td>
</tr>
<tr>
<td>• Ensure that the overall shape of visualization is not too abstract. Make the overall shape of visualization resemble radial shape.</td>
<td>• Ensure that the animation speed (i.e., Sustained motion) corresponds to slowly increasing the shape size and colour saturation.</td>
</tr>
<tr>
<td>Glide</td>
<td>• Use “moving upward-right and right or upward-left or left” motion direction, and ensure that a motion path curvature of visualization is straight.</td>
</tr>
<tr>
<td>• Ensure that the overall shape of visualization looks linear instead of abstract</td>
<td></td>
</tr>
</tbody>
</table>
| Punch | Use either “bursting out from centre” or “moving towards centre” motion direction, and ensures that motion path curvature is straight.  
|       | Ensure that the overall shape of visualization is not too abstract. Makes the overall shape of visualization resemble either a radial or spherical shape.  
|       | Use red or red orange colour scheme with high colour intensity and colour value.  
|       | Ensure that quickly increasing colour saturation and shape size correspond to Sudden Time Effort.  

| Dab | Use either “moving towards centre” or “moving outwards from centre” motion direction with straight motion path curvature.  
|     | Ensure that the overall shape of visualization resembles a sphere.  
|     | Use red-purple colour scheme with low colour intensity but high colour value.  
|     | Ensure that quickly increasing shape size and (slightly) colour saturation correspond to Sudden Time Effort.  

| Wring | Use “moving from all directions towards centre” spirally motion direction with curving or meandering motion path curvature.  
|       | Ensure that the overall shape of visualization resembles a spiral.  
|       | Use blue-purple colour scheme with medium colour intensity and colour value to create a sense of Strong Effort.  
|       | Ensure that slowly increasing shape size and decreasing colour saturation (slightly) correspond to Sudden Time Effort.  

| Float | Use “moving upward, upward-left, and upward-right” motion direction, and ensure that the motion path curvature is curved and meandering.  
|       | Ensure that overall shape of visualization looks simple and resembles a non-linear shape  
|       | Use green, light-green or lime green colour scheme with medium colour intensity and high colour value in order to create a sense of Light Effort.  
|       | Ensure that slowly increasing shape size (slightly) and decreasing colour saturation correspond to Sustained Time Effort.  

| Slash | Use a randomly moving “outwards from centre to all directions” motion direction and ensure that the motion path curvature is angular and straight.  
|       | Ensure that the overall shape of visualization resembles an angular and somewhat abstract shape.  
|       | Use orange or orange red colour scheme with high colour intensity and colour value in order to create a sense of Strength.  
|       | Ensure that quickly increasing colour saturation and the shape size correspond to Sudden Time Effort.  

|     | Ensure that animation speed (i.e., Sudden motion) corresponds to quickly increasing the shape size and colour saturation.  

| Dab | Use either “moving towards centre” or “moving outwards from centre” motion direction with straight motion path curvature.  
|     | Ensure that the overall shape of visualization resembles a sphere.  
|     | Use red-purple colour scheme with low colour intensity but high colour value.  
|     | Ensure that quickly increasing shape size and (slightly) colour saturation correspond to Sudden Time Effort.  

| Wring | Use “moving from all directions towards centre” spirally motion direction with curving or meandering motion path curvature.  
|       | Ensure that the overall shape of visualization resembles a spiral.  
|       | Use blue-purple colour scheme with medium colour intensity and colour value to create a sense of Strong Effort.  
|       | Ensure that slowly increasing shape size and decreasing colour saturation (slightly) correspond to Sudden Time Effort.  

| Float | Use “moving upward, upward-left, and upward-right” motion direction, and ensure that the motion path curvature is curved and meandering.  
|       | Ensure that overall shape of visualization looks simple and resembles a non-linear shape  
|       | Use green, light-green or lime green colour scheme with medium colour intensity and high colour value in order to create a sense of Light Effort.  
|       | Ensure that slowly increasing shape size (slightly) and decreasing colour saturation correspond to Sustained Time Effort.  

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|       | Use orange or orange red colour scheme with high colour intensity and colour value in order to create a sense of Strength.  
|       | Ensure that quickly increasing colour saturation and the shape size correspond to Sudden Time Effort.  

|     | Ensure that animation speed (i.e., Sudden motion) corresponds to quickly increasing the shape size and colour saturation.  

| Dab | Use either “moving towards centre” or “moving outwards from centre” motion direction with straight motion path curvature.  
|     | Ensure that the overall shape of visualization resembles a sphere.  
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|       | Ensure that slowly increasing shape size and decreasing colour saturation (slightly) correspond to Sudden Time Effort.  

| Float | Use “moving upward, upward-left, and upward-right” motion direction, and ensure that the motion path curvature is curved and meandering.  
|       | Ensure that overall shape of visualization looks simple and resembles a non-linear shape  
|       | Use green, light-green or lime green colour scheme with medium colour intensity and high colour value in order to create a sense of Light Effort.  
|       | Ensure that slowly increasing shape size (slightly) and decreasing colour saturation correspond to Sustained Time Effort.  

| Slash | Use a randomly moving “outwards from centre to all directions” motion direction and ensure that the motion path curvature is angular and straight.  
|       | Ensure that the overall shape of visualization resembles an angular and somewhat abstract shape.  
|       | Use orange or orange red colour scheme with high colour intensity and colour value in order to create a sense of Strength.  
|       | Ensure that quickly increasing colour saturation and the shape size correspond to Sudden Time Effort.  

|     | Ensure that animation speed (i.e., Sudden motion) corresponds to quickly increasing the shape size and colour saturation.  

| Dab | Use either “moving towards centre” or “moving outwards from centre” motion direction with straight motion path curvature.  
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| Dab | Use either “moving towards centre” or “moving outwards from centre” motion direction with straight motion path curvature.  
|     | Ensure that the overall shape of visualization resembles a sphere.  
|     | Use red-purple colour scheme with low colour intensity but high colour value.  
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|       | Use blue-purple colour scheme with medium colour intensity and colour value to create a sense of Strong Effort.  
|       | Ensure that slowly increasing shape size and decreasing colour saturation (slightly) correspond to Sudden Time Effort.  

| Float | Use “moving upward, upward-left, and upward-right” motion direction, and ensure that the motion path curvature is curved and meandering.  
|       | Ensure that overall shape of visualization looks simple and resembles a non-linear shape  
|       | Use green, light-green or lime green colour scheme with medium colour intensity and high colour value in order to create a sense of Light Effort.  
|       | Ensure that slowly increasing shape size (slightly) and decreasing colour saturation correspond to Sustained Time Effort.  

| Slash | Use a randomly moving “outwards from centre to all directions” motion direction and ensure that the motion path curvature is angular and straight.  
|       | Ensure that the overall shape of visualization resembles an angular and somewhat abstract shape.  
|       | Use orange or orange red colour scheme with high colour intensity and colour value in order to create a sense of Strength.  
|       | Ensure that quickly increasing colour saturation and the shape size correspond to Sudden Time Effort.  

|     | Ensure that animation speed (i.e., Sudden motion) corresponds to quickly increasing the shape size and colour saturation.  

| Dab | Use either “moving towards centre” or “moving outwards from centre” motion direction with straight motion path curvature.  
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| Wring | Use “moving from all directions towards centre” spirally motion direction with curving or meandering motion path curvature.  
|       | Ensure that the overall shape of visualization resembles a spiral.  
|       | Use blue-purple colour scheme with medium colour intensity and colour value to create a sense of Strong Effort.  
|       | Ensure that slowly increasing shape size and decreasing colour saturation (slightly) correspond to Sudden Time Effort.  

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|       | Ensure that overall shape of visualization looks simple and resembles a non-linear shape  
|       | Use green, light-green or lime green colour scheme with medium colour intensity and high colour value in order to create a sense of Light Effort.  
|       | Ensure that slowly increasing shape size (slightly) and decreasing colour saturation correspond to Sustained Time Effort.  

| Slash | Use a randomly moving “outwards from centre to all directions” motion direction and ensure that the motion path curvature is angular and straight.  
|       | Ensure that the overall shape of visualization resembles an angular and somewhat abstract shape.  
|       | Use orange or orange red colour scheme with high colour intensity and colour value in order to create a sense of Strength.  
|       | Ensure that quickly increasing colour saturation and the shape size correspond to Sudden Time Effort.  

|     | Ensure that animation speed (i.e., Sudden motion) corresponds to quickly increasing the shape size and colour saturation.  

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- In the beginning of motion, create a spiral or twist motion with fade in transition at upward left or upward right position of the screen.
- Ensure that a motion path curvature generated by a spiral or twist motion is curved.
- In the middle to the end of motion, use “moving outwards from centre to all directions” motion direction and ensure that path curvature is straight.
- Ensure that the overall shape of visualization is not too abstract and resembles a spiral in the beginning of visualization.
- Use the yellow-orange, yellow-green or light green colour scheme with medium colour intensity and high colour value.
- Ensure that animation speed (i.e., Sudden motion) corresponds to quickly decreasing shape size and increasing colour saturation.
- Use accelerated motion in the beginning of visualization sequence (i.e., spiral or twist motion) and Sustained motion (i.e., moving outwards from centre to all directions) for the rest of the visualization sequence.

Note. These design criteria are based on holistic analysis, microanalysis, and the eight visual variables grounded in Appendix D.

7.5. Use Case Scenarios of Design Criteria for Representing Movement Quality

In the previous section, I presented the comparative analysis results for each Basic-Effort-Actions visualization among systems and suggested design criteria for representing the eight Basic-Effort-Actions or eight movement qualities. However, these design criteria are not intended to dictate precisely how one should engage with the complete design process. Rather, it presents a simple instruction to guide one in the early stages of designing the representation of movement quality or the eight Basic-Effort-Actions. This section presents three use case scenarios in which the design criteria can be used as a design guideline to support aesthetically communicated expressive movement qualities.

7.5.1. Communication Design

In communication design or graphic design practice, design students in a design foundation course are often required to study compositional arrangement of basic two-dimensional design. This is done to learn how to compose and use visual language to communicate ideas in various media related to visual communication (e.g., books, magazines, newspapers, corporate identities, posters, packaging, environmental graphics, and websites). In class practice, the students often learn how to use visual
language to communicate nonverbally, such as body language and posture, gestures or emotional expression. For instance, they may use basic geometric elements to create design compositions representing emotional expression (e.g., angry, sad, or disgusted) or to convey the meaning of given words (e.g., frustrated, relax, cold, and warm).

In this scenario, the student can use this design guideline as a part of visual communication practice to (1) create compositions that represent various qualities of movement (similar to an emoticon\(^\text{12}\)), (2) contribute further discussion about designing the representation of human gesture quality or (3) experiment with design principles and strategies for conveying different qualities of human motion. For LMA Effort theory, the design criteria can also be used as a guideline to aesthetically create a new set of symbols and compare them with existing symbols used to describe the concept of LMA Effort or the eight Basic-Effort-Actions (Fig. 7.3 a). It could also be developed and used with dance notation\(^\text{13}\) systems, such as Labanotation (Figs. 7.3 b & c). In doing so, this design criteria bridges the gap between human movement analysis and visual communication design.

![Symbols in LMA](http://commons.wikimedia.org/wiki/File:Labanotation2.JPG)\(^{12}\), ![Labanotation signs set 2 by Huster, 2007](http://commons.wikimedia.org/wiki/File:Labanotation4.JPG)\(^{13}\) Used under the public domain license.

**Figure 7.3.** Symbols in LMA: (a.) Symbols used to describe the eight Basic-Effort-Actions. (b. & c.) Symbols used in Labanotation


\(^{12}\) Emoticon is a representation of a facial expression used in electronic communications to convey feelings or intended tone (oxforddictionaries.com, 2014).

\(^{13}\) Dance notation, similar to music notation, is a symbolic representation used for representing, composing, decomposing or recording human dance movement, such as Lababnotation (Guest, 1989).
Figure 7.4 presents examples of visual composition using the design guideline for representing Float quality. Figure 7.5 presents more complex visual patterns of Float quality, which is used in communication design art works.

Figure 7.4. Example of Float quality visual composition

*Note.* Created by srinlim, used with permission.
Figure 7.5. Example of complex visual patterns of Float quality

Note. Created by srinlim, used with permission.

7.5.2. Abstract Animation

Abstract animation is a type of animation often employed to evoke the affective experience in various research fields, such as algorithmic art, generative art, game design, information visualization or virtual reality. For instance, in information visualization research, it is used to investigate how various fundamental properties of motion influence viewers’ affective experience (e.g., Feng, 2014; Lockyer et al., 2011; Lockyer et al., 2012). In generative art, it is used to evoke viewers’ aesthetic perception (e.g., Bohnacker et al., 2012; Reas and McWilliams, 2010; Tarbell, 2010).
In this use case scenario, *motionscapes*,\(^{14}\) a visualization system used in affective motion experience research,\(^{15}\) is a good software candidate for applying the design criteria as a guideline to create abstract animation of movement quality. This is because it uses simple particle system and has similar motion properties to those used in EMVIZ comparative analysis, such as speed, direction, shape, path curvature and size. Figure 7.6 presents a screen capture of the *motionscapes* system.

**Figure 7.6. A screen capture of motionscapes system created by Unity 3D**
*Note.* From Feng (2014); used with permission.

The eight design criteria can be adapted with the existing features of *motionscapes* by creating a new interface design that allows users to (1) adjust Space, Weight, and Time parameters to generate specific motion pattern and (2) save the settings, as well as load predefined parameters in order to playback the animation. Figure 7.7 presents a sketch interface of *motionscapes* and Figure 7.8 presents the examples of Punch and Float visualizations generated by *motionscapes* after applying the design guideline.

\(^{14}\) Motionscapes is an affective motion visualization system that generates different motion patterns to evoke viewer affective experience based on different types of motion properties, such as speed, direction, shape, path curvature or scale (Feng, 2014).

\(^{15}\) See: Feng (2014), The Affective Affordance of Motionscape.
Figure 7.7.  The sketch interface of motionscapes
Note.  Parameter adjustment interface (left) and loading predefine parameter interface (right).

Figure 7.8.  Examples of Punch and Float Visualizations
Additionally, the design criteria can also be explored in the generative art area by adapting or applying it with a particle-based generative algorithm created by computational artists such as Sand Traveller by Jared Tarbell, Network B by Casey Reas, and Immaculate Collision by Mark J. Stock (Fig 7.9). This process will help artists or designers to extend the creative use of the movement quality design guideline in the generative art and design domain.

Figure 7.9. Examples of generative art works: (a) Sand Traveller; (b) Network B; and (c) Immaculate Collision

7.5.3. Movement Analytic

In human computer interaction (HCI), computer animation or sports and health research, human movement has been extensively researched in order to understand the qualitative characteristics of movement. This has resulted in various tools, technologies, and computation techniques for capturing human movement information (e.g., position, velocity, acceleration of specific body parts, and movement trajectory). However, the information is captured or recorded through various sensors (e.g., motion capture, accelerometers, and video capture) and these data provide little information about underlying movement characteristics, such as movement quality. Movement characteristics data requires human experts to interpret and elaborate it in order to use this knowledge and apply it to other fields. Thus there is a need for an analytical tool for visualizing this type of information in order to facilitate researcher observation and analysis of different types of movement features.
In this scenario, I chose Mova, an open-source web-based movement analytic platform, to exemplify how the design criteria for representing movement quality can be used in the movement analytic research area. Figure 7.10 presents a screen capture of the Mova: Movement Analytics Platform.

![Mova: Movement Analytics Platform](image)

**Figure 7.10. A screen capture of Mova: Movement Analytics Platform**

*Note.* See http://www.sfu.ca/~oalemi/movan

Mova is a good candidate for applying the design criteria usage because it visualizes the eight Basic-Effort-Actions or movement quality data captured from the motion capture system. Mova allows the researchers to observe and compare the eight Basic-Effort-Actions captured from motion capture data through the Figure sketch animation and the list of features extracted from the movement, such as speed, acceleration, jerk, direct segments, and sample annotation from different parts of body (Alemi et al, 2014). The system assists researchers by visualizing each motion feature in

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16 Mova is a movement analytic platform which integrates a set of extensible feature extraction methods with a visualization engine with an interactive environment. See: (Alemi et al., 2014)

17 The data was captured on May 23rd 2013 during the movingstories May residency, described in Chapter 5, section 5.3.
parallel and allows them to easily compare and contrast the similarities and differences of different motion features.

Mova allows researchers to experience eight movement qualities in a form of body representation (i.e., Figure sketch animation) and motion features extracted from different parts of the body. However, it is possible include a feature that allows researchers to compare and contrast the movement quality represented in a form of moving body with the abstract animation. For instance, creating a plugin that displays abstract visualization on the right side of figure sketch animation timeline (Fig. 7.11) and maps the data (e.g., speed, acceleration or position) derived from the motion capture system with the parameters of visualization. In this process, the design criteria for representing eight movement qualities can be adapted and combined with data derived from the motion capture system to create abstract representations of movement quality. This feature allows researchers to compare movement quality from two different perspectives and create further discussions about motion features of the abstract animation. Figure 7.11 presents a sketch interface that allows researchers to compare qualities of movement captured from the human body with the abstract visualization generated by the design criteria.

![Figure 7.11. A sketch interface of Mova with abstract animation feature](image-url)
7.6. Limitation

The design criteria has some limitations, described as follows:

- The design criteria is not intended to dictate how one should engage with the complete design process. Rather, it provides guidance in the early stages of designing the representation of movement quality or the eight Basic-Effort-Actions.

- It is very important to note that the design criteria for representing movement quality is limited to the eight Basic Effort Actions within a Diagonal Scale\(^{18}\) or eight movements in postural effortful actions that always appear at the extremes of personal space (i.e., corner of an imagery cube) (see Fig. 7.12). The design criteria is not intended to provide guidance for representing movement quality of gestural actions although LMA Effort can be used to describe the qualities of both types of actions (i.e., postural effortful actions and gestural actions). The limitation of design criteria focus to postural effortful actions is because the movement quality recognition system (EFFORTDETECT) used in this research was trained to classify the eight Basic-Effort-Actions from postural effortful actions. Thus the direction motion of some Basic-Effort-Actions described in the design criteria (e.g., Float, Glide or Flick) are only meant to be used to represent the Basic-Effort-Actions in postural effortful actions. However, the design criteria can be adapted and extended to represent the quality in gestural actions but more research is needed.

Figure 7.12. Laban’s three-dimensional cube, the dimensional cross within the cube, the Diagonal Scale, and the eight Basic-Effort-Actions

Note. See Bradley (2008).

\(^{18}\) A diagonal scale consists of four diagonals that cross the body from the corner of an imagery cube to the exact opposite corner.
Chapter 8.

Discussion and Conclusions

In this chapter, I discuss the research findings, new knowledge, and implications gained from practice-based art research in this research. The chapter begins by revisiting the core research goals and questions, followed by a summary of artistic visualization and EMVIZ system design processes. Each section presents (1) a brief summary about what was done and research contributions in each part of the practices, (2) a comparison of research findings with other work in the fields (if available), and (3) suggestions for further improvements. Finally, the conclusion section briefly revisits the most important findings, highlights how the findings advance human movement study and the artistic visualization domain, and presents study limitations and recommendations for future work.

8.1. Research Goals and Questions Revisited

A key goal of this practice-based research was to create visual representations of movement quality information captured from bodily motion. In this section, I discuss how my research and results have answered the following research questions:

1. How can Laban Movement Analysis (LMA) be used as a semantic design resource for visualizing movement qualities or Laban Effort qualities by:

   1.1. using metaphor theory to outline potential visual mapping to represent Laban Effort qualities, specifically the Basic-Effort-Actions?

   1.2. creating a set of design heuristics for abstract visual representation of movement quality based on the analysis of movement experts’ perception of the communicative ability of different visual mapping approaches?
8.1.1. Research Question 1.1

To answer Research Question 1.1, I developed a series of visualization systems called EMVIZ, using LMA as an underlying model to capture, represent, and map movement quality to a visualization system. In the EMVIZ systems design process, LMA Effort was used as a design resource at the metaphorical level to provide a description and definition of movement characteristics for transforming data into visual forms. I explored the creative use of metaphor by mapping characteristics of LMA Effort to visual design properties—crossing modalities from human movement quality (gesture mode) to visualization (pictorial signs mode). This resulted in design descriptions used for describing visual structures and motion properties of the eight Basic-Effort-Actions or movement qualities. In EMVIZ (L), I explored generative computation and mapped eight design descriptions to the L-system’s generative grammar for generating visualizations. In EMVIZ (Sketch), I translated eight design descriptions into computation for visual generation. In EMVIZ (Motion-Agent), I applied eight design descriptions to a computational model of autonomous agents-based system to generate visual representations of movement quality. These different mapping approaches resulted in three potential design strategies for representing eight movement qualities through abstract expressive animations or visualizations.

In Chapter 2, the literature review indicated that LMA has been used in many research areas, but there was no contribution towards the application or utilization of LMA within the visualization domain. This thesis’ findings in answer to Research Question 1.1. contribute to LMA utilization in computing literature, specifically within the visualization domain. These contributions are described as follows:

1. Three EMVIZ system design processes contribute new knowledge by describing and illustrating how LMA Effort and movement expertise can be used as a design resource for modifying and adapting to the design and application of more richly articulated human movement knowledge within the visualization domain.

2. Second, this practice-based research extends the LMA Effort framework by creating visual representation of movement qualities, allowing the practitioner to visually experience movement qualities described in LMA Effort theory. This contribution can be compared to Synesketch (Krcadinac et.al, 2013) or Wee Feel Fine (Kamvar & Harris, 2011), works that aimed to create the visual representation of human emotion, allowing people to experience emotion through abstract visual forms or simple graphical forms.
3. Third, in human movement visualization research, there are few contributions to visualized information obtained from movement observation and experience, such as in *ActionPlot* (Carlson et al., 2011), *MotionBank* (The Forsythe Company, 2010-2013), and *Synchronous Objects* (Forsythe, 2009; Palazzi & Shaw, 2009). Thus, this research contributes to the human movement visualization research literature.

### 8.1.2. Research Question 1.2

To answer Research Question 1.2, I conducted a user study by recruiting Certified Laban Movement Analysts (CMAs) to evaluate the communicative ability of the three design strategies for visualizing movement qualities. User study results demonstrated that each EMVIZ system is good at communicating different movement qualities. The comparative analysis method was incorporated with user study results in order to critique, analyze, and select the best design strategies for representing eight movement qualities. This resulted in a set of design heuristics for visualizing movement quality through abstract expressive animations or visualizations. This finding provides a descriptive design instruction regarding how to visually present the concept of eight movement qualities described in LMA Effort, contributing new knowledge that can be further explored further in other research areas, such as communication design, abstract animation, and movement analytics.

### 8.2. Artistic Visualization

In Chapter 2, I reviewed the state of the art of visualization research and the characteristics of the artistic visualization. This resulted in a descriptive framework for describing and analyzing the characteristics of artistic visualization (i.e., data type, artistic goal, design process, and outcome and visual experience). This framework was used to analyze and describe the characteristics of existing artistic visualization projects, thus allowing comparison between different artistic visualization projects. In addition, four characteristics of artistic visualization were used to frame the direction or approach of this thesis’ practice-based research (i.e., exploratory design or visualization exploration [see Chapter 3, section 3.2]). For instance, the artistic visualization design process focuses on the experimentation of theoretical model usage, data mapping design or computation. This practice-based research uses the artistic visualization design approach as a guideline in the movement quality visualization design process.
This artistic visualization framework contributes to the visualization research literature by providing a better understanding of the characteristics of artistic visualization as well as a comparison of selected visualization projects inspired by new media art, digital art, interactive art, visual art, social sciences, computational art, and generative art.

One possible criticism of this framework may be its focus on aesthetic criteria of sublimity (i.e., readable [pragmatic] or non-readable [artistic]) rather than the visualization's aesthetic outcome. However, philosophical discussion of aesthetics, qualities of sensual perception or beautification of the visualization is beyond the scope of this thesis. This issue could be further explored in future work in order to construct a more complete framework for describing and analyzing aesthetic qualities of artistic visualization projects.

### 8.3. EMVIZ System Design

#### 8.3.1. Movement Quality Recognition System

EMVIZ used a real-time wearable sensor classifier supervised learning system called EffortDetect, that applied the LMA model to extract movement qualities information from a moving body via a continuous stream of Laban Basic-Effort-Actions. However, this data stream contained only the predictions and confidence values of the eight Basic-Effort-Actions (i.e., one of eight movement qualities) and no other associated information (e.g., speed, velocity, position or direction). It would have been better if EffortDetect was able to provide these additional data as well, because such information can be useful in the visualization design process. For instance, a stream of speed, velocity, position, and direction data values can be mapped with Time Effort and Space Effort computational parameters. This could solve the issue of “multiple Effort parameter values presented in the visualization” reported by participants (see Chapter 6). If the EMVIZ system used data on speed, velocity, position, and direction captured from the moving body instead of fixed or simulated values defined by the visualization system,

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1 Multiples Effort is the problem of two Effort parameter values being perceived in the same visualization sequence (e.g., Sudden and Sustained).
then this could help participants to easily identify Effort parameter values in the visualization associated with a particular body movement.

EffortDetect can be incorporated with different types of sensor technologies (e.g., Microsoft Kinect sensor or Motion Capture system) to obtain fundamental movement information about the human body, such as speed, velocity, position and direction. In EMVIZ (Motion-Agent), a Microsoft Kinect sensor was incorporated with EffortDetect to provide arm position data (X, Y, Z) in association with a stream of Basic-Effort-Actions, allowing visualization to move in the same direction as a dancer’s arm position. This integration demonstrated the possibilities for further exploration on applying LMA Effort with two or more types of sensors to capture movement qualities information from the moving body. This extends to other research that uses one sensor technology (e.g., biometric sensors, infrared sensor, pressure sensor, motion capture or accelerometers) to analyze and capture movement quality information from a moving body, such as Alaoui et al. (2012), Rett et al. (2010), Schiphorst (2009), and Swaminathan et al. (2009).

8.3.2. Mapping Design Strategy

8.3.2.1. Metaphoric Mapping

The EMVIZ system design used the metaphor theory to explore the possibilities for transforming the meaning embedded in a stream of data (i.e., eight movement qualities classified by supervised learning algorithm) into visual representation. The Visaphor framework (Cox, 2008) was used as a guideline for describing the data transformation process (i.e., mapping source domain to target domain). In contemporary visualization, metaphor is often used as a concept to develop effective computation techniques for transforming complex data structures or information patterns into easily perceived visual representations. For instance, the characteristics of a tree were used as a reference to develop a “treemap” for representing hierarchical data using nested rectangles. The EMVIZ system design used the metaphor concept to identify similarities between source domain characteristics (i.e., movement quality) to target domain characteristics (i.e., visual forms). The similarities between two domains were mapped and experimented on with computational parameters for visual generation.
The EMVIZ mapping process process illustrated (1) the artistic visualization mapping design described by Ramirez (2008) and (2) the interpretive mapping technique and extrinsic data focus described by Lau and Moere (2007) and Moere (2007). This contributed new knowledge and expanded the visualization literature by describing how metaphor can be used in the mapping design process of artistic visualization.

8.3.2.2. Colour Mapping

In mapping movement quality to colour, one encounters the problem of subjectivity because no previous research has explored the relationship between the perception of different movement qualities and colour psychology. However, this practice-based research used an exploratory design approach to experiment with different mapping strategies and extend the creative use of colour in the visualization domain.

Inspired by Kandinsky’s theory, EMVIZ (L) colour mapping explored the connections between the expressivity of movement and colour perception. This colour mapping strategy demonstrated a new mapping approach where the meaning of colour defined by Kandinsky’s theory could be mapped with the characteristics of Effort parameter values defined by Rudolf Laban. EMVIZ (Sketch) and EMVIZ (Motion-Agent) used similar colour mapping models based on Itten’s elements of colour. EMVIZ (Sketch) mapped the meaning of Effort parameter values with cold-warm colours as defined by Itten’s colour model. In contrast, EMVIZ (Motion-Agent) mapped colour characteristics defined by Itten’s colour model and Goethe’s primary colour circle with the characteristics of emotion and movement quality. These two colour mapping strategies presented alternative mapping design strategies to EMVIZ (L). Altogether, these three design strategies contributed to the creative and expressive use of colour in visualization and LMA literature.

Although participant feedback identified some issues with these three colour mapping design strategies (e.g., colour subjectivity or unclear colour transition [see Chapter 6]), they can be further explored and solved by conducting a user study on colour and movement qualities perception to identify the best represented colour for the eight Basic-Effort-Actions or eight movement qualities. In emotion and colour perception research, da Pos and Green-Armytage (2007) studied how people of different ages and
cultural backgrounds associated colours with emotive facial expressions based on Ekman’s six basic emotions (i.e., happiness, fear, sadness, surprise, disgust, and anger). Pos & Green-Armytage’s study design could be replicated and adapted to the design study of movement qualities and colour perception by asking CMAs (i.e., movement analysts) to associate colours with the eight Basic-Effort-Actions.

8.3.2.3. Computational Design

EMVIZ (L) used L-system generative grammar to generate visualization. This computation design approach extended the creative use of L-system in design and computing because the L-system is often used in computer graphics for simulating the growth process of plants or organic forms, such as in Turbulence (1995), Morphogenesis (2001-2004), and Bloom (2006) (McCormack, 2004; Whitelaw, 2004). It has also been used in architectural design for generating architectural surface and form (e.g., Hansmeyer, 2003 or O’Reilly and Hemberg, 2007). However, the L-system has never been applied to the human movement and visualization domain. The EMVIZ (L) computation design strategy offered a new mapping approach and described how L-system generative grammar can be mapped with Effort parameter values for generating visualizations.

EMVIZ (Sketch) used sketching technique to (1) capture the characteristics of movement quality from a dancer’s performance of the eight Basic-Effort-Actions, (2) represent movement quality characteristics in abstract visual forms and compositions, and (3) create descriptions of the eight Basic-Effort-Actions based on the sketch of abstract visual forms and compositions. Eight descriptions were used to construct eight different computations for representing movement quality. The EMVIZ (Sketch) computational design presented the integration of my observations and experiences in theory and practice in visual art discipline. This resulted in an alternative computation design approach that can be adapted and used as a part of programming practice.

EMVIZ (Motion-Agent) used a computational model of boids system or autonomous flocking agents to generate visual representations of movement quality. The boids system is often used to simulate realistic representations of animal behaviour (e.g., flocks of birds, schools of fish or herds of animals) in computer animation. It has been used in the visualization domain to represent complex time-varying datasets
(Moere, 2004), meteorological data (Hutzler et al., 2000) or student population fluctuation (Milam & Pasquier, 2008). In interactive arts and visualization, this agent-based system has been used for simulating visualization responding to dance performances of movement interaction, such as in Swarms (2008), Swarm on Stage (2009) or Dancing With Swarming Particles (2011) (Besig, 2008; Besig and Unemi, 2009; Carvalho and Regev, 2011). However, it never been used to represent movement information. Thus the EMVIZ (Motion-Agent) computation design approach presented a new mapping approach and described how to map boids computational parameters with Effort parameter values to generate different motion patterns. This contributed new knowledge to the research literature in the movement interaction and visualization field.

8.3.2.4. Study Design

Twelve CMAs were recruited to evaluate three EMVIZ systems using an online survey and within-group study design wherein each participant performed under all sets of conditions in the study.

The LMA Effort framework and CMAs’ observational skills were validated in order to ensure that the EMVIZ systems evaluation was reliable and valid. This thesis’ LMA validation contributed to computing research literature (specifically HCI) and generated discussions about the reliability and validity of research using CMAs’ expertise to evaluate research projects. In this study, there might be some criticism that the evaluation task is too easy such that whomever studied LMA is able to identify eight movement qualities in movement sequences. However, such assumptions cannot be made until the experiment is done. This thesis’ LMA validation used a very simple evaluation task and presented an initial step to evaluating LMA Effort and CMAs’ observational skills, allowing researchers to use this study’s findings for further exploration.

The three EMVIZ systems were evaluated via an online survey and analyzed using descriptive statistics, CMH test, and ANOVA. Although the study produced satisfying results, the EMVIZ evaluation study design can be improved by increasing participant numbers, re-designing the online survey interface, and performing onsite user study research.
1. Increasing participant numbers will provide stronger statistical results. The ideal sample size would be 20 CMAs. In this study, participants were recruited via email invitation and almost of them lived outside of Canada. Fifteen people participated in the study and 12 participants completed the survey over a two-month period for data collection. Thus, recruiting 20 CMAs is a very challenging task because of this thesis’ time limits. However, in future research, this task can be achieved by expanding the time frame for data collection.

2. According to participant feedback, improving the online survey interface will make the evaluation task easier to perform. In this online survey, participants reported that they had to watch each visualization video and each movement video in two separate windows, causing some participants to have difficulty finding links between phrases in the visualization and movement videos. This problem can be solved by designing an interface that allows visualizations and movement sequences be compared side-by-side. This will make the process of Basic-Effort-Actions visualization identification easier than the previous online survey interface.

3. Performing onsite user study research will (1) help minimize fatigue effect caused by multiple experimental tasks in the study and (2) allow researchers to obtain more participant feedback. In the EMVIZs evaluation online survey, all participants were required to do five experimental tasks and some participants may have become tired or frustrated because of the experiment session’s length. Although the survey had a feature that allowed participants to take a break when they got tired (i.e., save data at any time and return to the survey later), this feature may not have been used because participants wanted to finish the survey or did not recognize that they were getting tired. Thus, I recommend performing onsite user study research and having the participants take a break during the experiment. Additionally, performing onsite user study research will provide more inclusive participant feedback information because an interview method can be used. Future research can use these suggestions to conduct more effective user studies.

8.4. Conclusions

This practice-base research presented three different versions of EMVIZ, an artistic system for visualizing movement quality, using LMA Effort as an underlying movement framework to describe the design process. In this process, I demonstrated (1) how to integrate EffortDetect with EMVIZ system design, (2) how metaphor and LMA Effort were used to describe the mapping between movement qualities and visual properties, (3) how I chose an expressive use of colour and computation, and (4) how I mapped them to movement quality data for generating visualization. This process advances current knowledge of human movement and visualization by bridging human movement study in art, design, and computation with the artistic visualization domain.
Artists and researchers who are interested in applying LMA Effort to their artistic or creative works in digital technology contexts, specifically movement generated visualization (e.g., interactive arts, dance performance or artistic visualization), can use the design approaches presented in this thesis as a reference for further exploration. Additionally, this thesis generated a set of design criteria for visualizing movement qualities that can be used for further exploration such as comparing design guidelines for representing movement quality with the design strategy and motion properties for generating affective motion pattern or visualization that convey human emotion.

8.4.1.  Limitations

This practice-based research has three limitations, summarized as follows:

First, this practice-based research is limited to visualizing eight movement qualities or the eight Basic-Effort-Actions in the postural effortful actions or the crystallization of Effort (i.e., the moment in movement that punctuates expression and gesture or action [Schiphorst, 2008]) rather than the quality of gestural actions. For instance, moving the right arm downwards and leftwards with whole body movement to express Punch Effort quality is different from the gestural action of reaching for a glass of water to take a drink with Punch Effort quality. This example illustrates two different aspects of Punch (i.e., the crystallization of Effort and the quality of gestural action). This thesis is limited to representing the eight Basic-Effort-Actions in the crystallization of Effort because EffortDetect (i.e., the recognition system) was trained to classify the eight Basic-Effort-Actions in crystallized form, not the Effort or quality of gestural actions.

Second, the set of design heuristics for visualizing movement quality derived from this thesis’ user study and comparative analysis is not intended to instruct on how one should engage with the complete design process. Rather, it provides guidance in the early stages of designing the representation of movement quality or the eight Basic-Effort-Actions. Therefore, further exploration and adaptation are needed in order to use this guideline.

Third, the study design presented in this thesis is limited to measuring the communicative ability of three EMVIZ visualization systems via online survey using inferential statistics to validate hypotheses and descriptive statistics to support the
comparative analysis process. It provides the early stages of evaluating the representation of movement quality or the eight Basic-Effort-Actions. For further analysis, qualitative techniques (e.g., interview or focus group) are more suitable techniques used for understanding participant experiences. For instance, how and why participants selected or matched the eight Basic-Effort-Actions visualizations with the movement sequences or which mapping variables (i.e., shape, size, colour, etc.) worked the best among three EMVIZ systems. Moreover, comparative deep reading study can also be performed in order to allow participants to compare the outcome of three EMVIZ visualizations.

8.4.2. Future Work

This practice-based research can be further explored in various areas for future work. These include visualizing the eight Basic-Effort-Actions in 3D sculpture, visualizing Effort or the quality of gestural actions, exploring and visualizing shape of movement, and designing an interactive system for dance education.

8.4.2.1. Visualizing the eight Basic-Effort-Actions in 3D sculpture

The eight Basic-Effort-Actions visualization can be further explored in 3D sculpture with the goal of capturing the aesthetic of movement quality by abstracting or transforming the concept of the eight Basic-Effort-Actions into a physical aesthetic object. This can be done by exploring the data mapping process using data captured from EffortDetect in combination with motion capture data.² When human movement quality is materialized into a sculpture, this tangible movement quality object offers new ways for the audience to experience the eight movement qualities in frozen form.

8.4.2.2. Visualizing Effort or the quality of gestural actions

In regards to visualizing Effort or the quality of gestural actions, this study extends the limitation of this thesis (i.e., representing the eight Basic-Effort-Actions through postural effortful actions or the crystallization of Effort). This can be further explored by collaborating with computer scientists and CMAs to design a recognition

² Such data is already available from the Movingstories May Residency research workshop at Intersection Digital Studio (IDS), Emily Carr University of Art and Design, Vancouver, CANADA.
system that (1) classifies Basic-Effort-Actions from gestural actions and (2) provides speed, velocity, position, and direction information. This further exploration will provide the quality of gestural actions data in association with information (i.e., speed, velocity, position, and direction) that can be used in the visualization design process.

8.4.2.3. Exploring and visualizing shape of movement

An interesting area for exploration is the visualization of movement shape based on LMA Shape components. This thesis explored LMA Effort utilization, specifically the eight Basic-Effort-Actions, within the visualization domain. Thus, it would be interesting to explore LMA Shape components that describe the invisible forms and elements of movement, such as basic forms of movement, mode of Shape change or Shape qualities. William Forsythe used video to demonstrate the concept of dance geometry or the imaginary geometrical shapes of movement\(^3\) (Forsythe, 2012). Similarly, LMA Shape components can be further explored to design a system that is able to artistically visualize different shapes of movement.

8.4.2.4. Designing an interactive system for dance education

The EMVIZ system can be further explored and used as an interactive visualization system in an introductory LMA class in dance education. A mobile device can be used instead of a wearable device (i.e., EffortDetect) because both devices use an accelerometer combined with supervised learning to classify movement quality. The EMVIZ system can be redesigned and implemented in mobile application. Thus, we can combine recognition and visualization systems into a single mobile application and use wireless technology to stream the visualization to a computer screen. This application can be used within an introductory LMA dance class that teaches LMA Effort theory by allowing students to download the application and use it to visually experience various qualities of movement described in LMA Effort while they are moving.

\(^3\) See more information in Forsythe (2008) at https://www.youtube.com/channel/UCvzEl4d5_SdUe3B6EITEFSA or (Downie et al., n.d.) at http://openendedgroup.com/writings/danceGeometry.html
References


Appendix A.

EMVIZ Design Documentation

A1. Eight Basic-Effort-Actions Videos

Punch: http://player.vimeo.com/video/67602469

Wring: http://player.vimeo.com/video/67603494  
Dab: http://player.vimeo.com/video/67600031

Flick: http://player.vimeo.com/video/67600474  
Float: http://player.vimeo.com/video/67601445

Glide: http://player.vimeo.com/video/67601609  
Slash: http://player.vimeo.com/video/67603493

Note. The movement sequence of Karen Studd performed the eight Basic-Effort-Actions (BEAs [4 times per BEA]).

1.1. EffortDetect system (30 sec video)  
1.2. A Stream of BEA Vectors Video

http://player.vimeo.com/video/103186427  
http://player.vimeo.com/video/103185283
A2. **EMVIZ (L) Materials**

*See Chapter 4 folder in Supplemental_Materials.zip*

- **Figure4.12_Supplemental_Materials**
  - **Images**
    - Emviz_suppfiles.pdf
  - **Videos**
    - BEA_Scale.mp4
    - Dab-SD.mp4
    - Flick-SD.mp4
    - Float-SD.mp4
    - Glide-SD.mp4
    - Press-SD.mp4
    - Punch-SD.mp4
    - Slash-SD.mp4
    - Wring-SD.mp4

- **Figure4.13_Supplemental_Materials**
  - Emixer_installation.pdf

- **Publications**
  - Conference_paper.pdf
  - DRHA_presentaiton.pdf
  - Irmacs_poster.pdf
A3. **EMVIZ (Sketch) Materials**

See Chapter 4 folder in Supplemental_Materials.zip

![Figure 4.18_Supplemental_Materials]

- **Dab**
  - Dab-1-SD.mp4
  - Dab-2-SD.mp4
  - Dab-3-SD.mp4
  - Dab-4-SD.mp4

- **Flick**
  - Flick-1-SD.mp4
  - Flick-2-SD.mp4
  - Flick-3-SD.mp4
  - Flick-4-SD.mp4

- **Float**
  - Float-1-SD.mp4
  - Float-2-SD.mp4
  - Float-3-SD.mp4
  - Float-4-SD.mp4

- **Glide**
  - Glide-1-SD.mp4
  - Glide-2-SD.mp4
  - Glide-3-SD.mp4
  - Glide-4-SD.mp4

- **Press**
  - Press-1-SD.mp4
  - Press-2-SD.mp4
  - Press-3-SD.mp4
  - Press-4-SD.mp4

- **Punch**
  - Punch-1-SD.mp4
  - Punch-2-SD.mp4
  - Punch-3-SD.mp4
  - Punch-4-SD.mp4

- **Slash**
  - Slash-1-SD.mp4
  - Slash-2-SD.mp4
  - Slash-3-SD.mp4
  - Slash-4-SD.mp4

- **Wring**
  - Wring-1-SD.mp4
  - Wring-2-SD.mp4
  - Wring-3-SD.mp4
  - Wring-4-SD.mp4
A4. **EMVIZ (Motion-Agent) Materials**

See Chapter 4 folder in Supplemental_Materials.zip

![Figure 4.27-4.28_Supplemental_Materials]

- **Dab**
  - Dab-1-SD.mp4
  - Dab-2-SD.mp4
  - Dab-3-SD.mp4
  - Dab-4-SD.mp4

- **Flick**
  - Flick-1-SD.mp4
  - Flick-2-SD.mp4
  - Flick-3-SD.mp4
  - Flick-4-SD.mp4

- **Float**
  - Float-1-SD.mp4
  - Float-2-SD.mp4
  - Float-3-SD.mp4
  - Float-4-SD.mp4

- **Glide**
  - Glide-1-SD.mp4
  - Glide-2-SD.mp4
  - Glide-3-SD.mp4
  - Glide-4-SD.mp4

- **Press**
  - Press-1-SD.mp4
  - Press-2-SD.mp4
  - Press-3-SD.mp4
  - Press-4-SD.mp4

- **Punch**
  - Punch-1-SD.mp4
  - Punch-2-SD.mp4
  - Punch-3-SD.mp4
  - Punch-4-SD.mp4

- **Slash**
  - Slash-1-SD.mp4
  - Slash-2-SD.mp4
  - Slash-3-SD.mp4
  - Slash-4-SD.mp4

- **Wring**
  - Wring-1-SD.mp4
  - Wring-2-SD.mp4
  - Wring-3-SD.mp4
  - Wring-4-SD.mp4

![Figure 4.29_Supplemental_Materials]

- Effort_Detect_Creativity_Cognition_Workshop.pdf
- Extended_abstract_workshop_paper.pdf
- Flow_brochure&Web.pdf
- Flow_Performance.pdf

![Publications]

- Eva_London_2013_paper.pdf
Appendix B.

User Study Materials

See Chapter 5 folder in Supplemental_Materials.zip

B1. Capture Data from the Study Materials Preparation Session

1. [32 videos of the eight BEAs]
   - Dab
     - dab1-SD.mp4
     - dab2-SD.mp4
     - dab3-SD.mp4
     - dab4-SD.mp4
   - Flick
     - flick1-SD.mp4
     - flick2-SD.mp4
     - flick3-SD.mp4
     - flick4-SD.mp4
   - Float
     - float1-SD.mp4
     - float2-SD.mp4
     - float3-SD.mp4
     - float4-SD.mp4
   - Glide
     - glide1-SD.mp4
     - glide2-SD.mp4
     - glide3-SD.mp4
     - glide4-SD.mp4
   - Press
     - press1-SD.mp4
     - press2-SD.mp4
     - press3-SD.mp4
     - press4-SD.mp4
   - Punch
     - punch1-SD.mp4
     - punch2-SD.mp4
     - punch3-SD.mp4
     - punch4-SD.mp4
   - Slash
     - slash1-SD.mp4
     - slash2-SD.mp4
     - slash3-SD.mp4
     - slash4-SD.mp4
   - Wring
     - wring1-SD.mp4
     - wring2-SD.mp4
     - wring3-SD.mp4
     - wring4-SD.mp4

2. [2 videos of the eight BEAs within Diagonal Scale]
   - BEA_Scale_1.mp4
   - BEA_Scale_2.mp4

3. [32 BEA movement profiles]
   - BEA_DabData.txt
   - BEA_FlickData.txt
   - BEA_FloatData.txt
   - BEA_GlideData.txt
   - BEA_PressData.txt
   - BEA_PunchData.txt
   - BEA_SlashData.txt
   - BEA_WringData.txt
   - BEA_Chart
B2. Online Survey Materials

Selected eight Basic-Effort-Actions movement and visualization videos:

4. Study Part 1 materials
   - movement1.html
   - movement2.html
   - movement3.html
   - movement4.html
   - movement5.html
   - movement6.html
   - movement7.html
   - movement8.html

5. Study Part 2-4 materials
   - 1. System A (EMVIZ[L])
     - visualization1.html
     - visualization2.html
     - visualization3.html
     - visualization4.html
     - visualization5.html
     - visualization6.html
     - visualization7.html
     - visualization8.html
   - 2. System B EMVIZ[Sketch]
     - visualization1.html
     - visualization2.html
     - visualization3.html
     - visualization4.html
     - visualization5.html
     - visualization6.html
     - visualization7.html
     - visualization8.html
   - 3. System C EMVIZ[Motion-Agent]
     - visualization1.html
     - visualization2.html
     - visualization3.html
     - visualization4.html
     - visualization5.html
     - visualization6.html
     - visualization7.html
     - visualization8.html
B3. Online Survey Data

- Online survey data
  - 1. results-survey44438.csv
  - 2. results-survey44438.xls
  - 3. Data-listing-analysis.rtf

1. Results-survey44438.csv (original output from online survey system)
2. Results-survey44438.xls (csv convert to xls file prepare for analysis)
3. Data-listing-analysis.rtf (original data read from the modified excel file)

- Example of data listings for statistical analysis

<table>
<thead>
<tr>
<th>Participant</th>
<th>row</th>
<th>Move_A</th>
<th>SpaceA</th>
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Participant feedback on systems A, B, and C

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<tr>
<td>ID 9</td>
<td>The correlations of the visualization to the actual movement sequences was difficult for me to draw conclusions about. The movement sequences were crystal clear; the visualization had cloudy elements. Each visualization seemed to dissipate into Indirect Effort. I did not associate the colors with the Efforts except for purple which seemed to have a Strong Weight quality I must say that drawing conclusions about connections was a bit of a guessing game for me.</td>
</tr>
<tr>
<td>B</td>
<td>My reactions are much like those of section 2. There was difficulty in matching BEAs to the visualizations. If these visualizations were generated from Karen's movements, it would perhaps been more conducive to finding connections if they could have been viewed simultaneously.</td>
</tr>
<tr>
<td>C</td>
<td>Instead of thinking of the Action Drive, I tried to identify Efforts in the visualizations first. Again, however, this was a guessing game for me.</td>
</tr>
<tr>
<td>Overall Comments</td>
<td>Perhaps having had some background in the visualization concepts could have been helpful. I felt as though I should have been easily able to identify the connections but could not. As stated, being able to match visualizations and movement sequences side-by-side might have made these clearer. I also wonder why the clips were not presented in numerical order.</td>
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| ID 11       | A To me, color didn’t matter at all. Dynamics certainly worked, but because they frequently changed (shift happens a lot), I had to decide which part of the sequence I should focus on to identify the BEA. (I assume that it is because the original movement sequence was so.) Visual appearance seemed to be very clear with Time Effort, but not quite with Weight Effort as it sometimes became recognizable associated with other Effort elements. For Space Effort, it was a little confusing for me to deal with both movements: the movement as a whole and the movement as an each part. For instance, some visualizations had a moment of "bursting" coming out from the center, and it seemed Indirect Space because the parts came out to all over the space with multi-focuses, but at the same time, the visualization of the trace of each part was so Direct in Space. Nevertheless, over all, the clarity of communication was quite positive, I think.  
B Some of the visualization worked with color this time, for instance, like giving a sense of Strong Weight through gradually darkening the color in the same tone. I had the same problem with System B in terms of deciding which moment of the sequence I should focus on for the identification because shift happens in a moment. In general, my impression was that System B was more abstract while System A was more representational, and it was much harder (and confusing) to identify BEA through System B. With System A, viewing each visualization was enough to figure out each Effort Action along with its own Effort configuration, but with System B, I had to view many of the visualizations over and over again to compare each other and get a relative sense of how each Effort element was realized in the different visualizations.  
C The visualization of System C wasn't quite effective for me to identify the BEA. The Time effort was actually "slow" or "fast" with Even phrasings rather than "Quick" or "Sustained" in the sense of Time factor in Effort. I interpreted Weight factor with more primary colors for Strong Weight and more pale colors for Light Weight, but it seemed a little arbitrary because the visualization itself didn't really give me a sense of Weight through the movement of the image and I tried to match the particular Effort factor with any component that could be encoded someway. Space Effort was the most confusing to me in terms of how to differentiate Direct from Indirect because most of them looked Indirect with the on/off kind of movement of clusters here and there. In general, System C was the hardest to communicate BEA through the visual representations. |
<p>| Overall Comments | I was thinking about the possibility of perceptual differences among participants from different cultures especially when the visual representation of BEA was more in an imagery level rather than a representational level with more movement cues. |</p>
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<th>Participant</th>
<th>System / Comment</th>
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| ID 14       | A Some Basic Effort Actions were very clear in this method but some seemed left up to interpretation and more difficult to convey. For example, I did not distinguish by color when I was observing the visualizations- I looked for qualitative differences in the movement of the patterns on the screen.  
B I found this system very challenging to identify the Basic Effort Actions. For example, the circular bubble-like shapes would move in a trail that seemed to use sustained time but the individual shapes would appear on the screen quickly. This also happened for me with Space Effort- the shapes' trajectory would seem to use direct space yet it would move in an indirect way on that direct path. I found this system a little frustrating! |
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<tr>
<td>ID 19</td>
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<tr>
<td>A</td>
<td>I thought these visualizations were quite beautiful and engaging. I felt pretty confident in my ability to distinguish Indirect from Direct Space, but less confident about Strong and Light Weight. I think perhaps I relied more on a spacial affinity (moving upward being associated with Lightness) more than the actual. I felt Space was the easiest to recognize. Time was harder and depended upon what part of the phrase I was paying attention to - it was sometimes hard to distinguish accelerating/decelerating from Sudden/Sustained.</td>
</tr>
<tr>
<td>B</td>
<td>The Space was harder to see in these. #6 felt like both a Press and a Glide to me - a Press on the way in and a Glide on the way out.</td>
</tr>
<tr>
<td>C</td>
<td>In V#5, it was the softness of the color that made me think of Light Weight. In V#6 it was the lingering after image that made me feel Sustainment - this was the only one that felt at all sustained to me. In V#7, it was the length of the lines that gave me the feeling of Strong Weight, while in V#1 it was the width of the lines that gave me that feeling. Weight Efforts were hard to distinguish.</td>
</tr>
<tr>
<td>Overall Comments</td>
<td>In many of these visualizations I felt an immediate connection to the words of the Effort Actions - I would think &quot;That looks like a Float&quot;. But then when I looked more specifically at the individual Efforts that I saw in the visualization it was harder to feel clear that I was seeing all three elements of Weight, Space and Time. I feel like I responded most to the overall shape of the visualization. I mostly felt like I wasn't paying too much attention to color, but in hindsight I think the color probably had more subconscious influence - and I think color influenced my perception of Weight quite a bit.</td>
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<tr>
<td>A</td>
<td>The visual appearance gave a strong sense of space effort for me, and the dynamics revealed time effort. The color gave me a sense of condensing moments, but overall, the images were difficult for me to actually match to the BEAs - I could not gather a sense of weight effort.</td>
</tr>
<tr>
<td>B</td>
<td>Once I assigned meaning to the bubbles vs the lines and popping vs. the unfolding, I had a system for decoding. The color and dynamics were very useful for weight and time and the bubbles vs. lines useful for space.</td>
</tr>
<tr>
<td>C</td>
<td>This one was much harder for me to find the space effort. The color allowed me to discover strength, the visual appearance seemed to suggest weight and the dynamics time. Overall, the clarity of communication was confusing for relating to the BEA's</td>
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<tr>
<td>Overall Comments</td>
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<tr>
<td>ID 40</td>
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<tr>
<td>A</td>
<td>System A seems to more clearly show scattering and gathering than BEA's, mostly because it was difficult for me to observe weight. It was also hard to 'match' to BEA's because each visualization seems to be a phrase of several parts (often 3 parts, beginning, middle and end.) Mostly, in 2.1, I matched phrasing of sudden/sustain over the time of the clip/visualization. In 2.2, this made it hard for me to list just one quality, as one visualization might start with suddenness, sustain in the middle, then accelerate at the end. Weight was not something I could observe with this system.</td>
</tr>
<tr>
<td>B</td>
<td>Phrasing was the key that helped me match the dancer's BEA's to the visualization. Scattering and gathering were very easy to see between the many elements in the visualization. Concentric direction, or unified direction was more perceived as direct, eccentric directions and diverse directions of elements were perceived as indirect by me. The fact that each visualization had a phrase that often included a 're recuperation' moment of the opposite element from the main statement helped me match the phrases to the dancer's BEAs (3.1), but made it harder to say in 3.2 only one of each polarized element--perhaps if the question had been about the main statement, or the majority of time, I would only have listed one of the polarized elements. It was hard to perceive weight in the visualizations.</td>
</tr>
<tr>
<td>C</td>
<td>I couldn't perceive differences in LMA terms in this system other than some were slightly more sudden than others. I didn't actually match the dancer to the visualizations but since the questionnaire won't let me go on without answering, I put in the values from previous systems, so my answers here really have NO BEARING on this visualization system.</td>
</tr>
<tr>
<td>Overall Comments</td>
<td>This took me much longer than 40 minutes. It is exciting to see if the ability of observers to reliably observe BEA's is validated. In terms of the visualizations, see my other comments. In a moving body, contrary directions are counterbalances to the main directions--I didn't get a sense of orderliness of counter-direction or counter-balance from the visualizations. Good luck!</td>
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<td>ID 28</td>
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<tr>
<td>A</td>
<td>Visual appearance is fine, color is fine, dynamics are unclear, dynamics are contradictive. For example, both sustained and sudden are included in several visualizations. Relativity is a big factor for me.</td>
</tr>
<tr>
<td>B</td>
<td>Visual appearance is okay but it seems like size begins to represent weight (large image for strong and small image for light). Again, most visualizations included both quick and sustained, and strong and light. Time seemed the clearest.</td>
</tr>
<tr>
<td>C</td>
<td>visual appearance was okay. Color was okay, Dynamics were not clear or there were multiple effort actions within each visualization. Clarity of communication was unclear</td>
</tr>
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Personally, I do not believe any of the visualizations (A, B, or C) demonstrate the Basic Effort Actions with real clarity. Most problematic in all examples is the weight effort. Strong never really felt strong, even in the eight sequences that Karen demonstrated.

Great project! Good luck with it!!! I'm looking forward to learning the results of your findings

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<td>ID 33</td>
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<tr>
<td>A</td>
<td>The challenge was to know what was the beginning of the phrase and what was the end. Visual appearance of what was imploding or exploding helped the most.</td>
</tr>
<tr>
<td>B</td>
<td>The ways in which the circles collided on one another, the brilliance of the colors, and the speed of how bubbles dissipated were my determining factors.</td>
</tr>
<tr>
<td>C</td>
<td>Highly subjective as I found the &quot;lines&quot; to be dictating. Phrasing, that is where lines began and where ended, were my guides.</td>
</tr>
<tr>
<td>Overall Comments</td>
<td>I am not sure of the validity as I did not necessarily find a one to one correlation but the system did not allow for that.</td>
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<tr>
<td>A</td>
<td>Red Color is helpful in indicating strength. Visualizations seem to attempt to poetry recuperation from the basic effort action which can be confusing. I see lots of overlap and room for interpretation...not completely objective by any means.</td>
</tr>
<tr>
<td>B</td>
<td>Even more frustrating. Not clear at all that each visualization was meant to match ONE basic effort action? Lots of guessing here.</td>
</tr>
<tr>
<td>C</td>
<td>all visualizations were variations of the same thing except number 8 which only varied in color and therefor gave me indication of STRONG. However I don't think everyone would have that interpretation.</td>
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<tr>
<td>Overall Comments</td>
<td>found this pretty tedious and took me way longer than estimate provided!</td>
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<tr>
<td>A</td>
<td>I found it very difficult for system A to depict qualities that are human. I found the relationship to place middle muddy because I was unsure where it was therefore spatial direction was hard to see, the color denoted the action but was difficult to follow it, dynamics was the easiest to see.</td>
</tr>
<tr>
<td>B</td>
<td>system B was easier to see spatially, the change in shapes of the visualizations also added to the understanding such as the circles for dab. The whole visual appearance was much clearer. Color did not seem to be a factor for me.</td>
</tr>
<tr>
<td>C</td>
<td>These were nearly impossible for me to detect and I probably guessed on most of these. Because of time constraints on my part I could not spend a great deal of time looking at this one and it frustrated me.</td>
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</table>
Overall Comments
This was a very interesting study and survey. I spent way more than the time that you had mentioned it would take however. Karen's slash and punch were awesome and all of her demonstrations were excellent. I was happy to participate. I do think the survey would have been a little easier to follow had the movements and visualizations been put in their order number. It got a bit easier as time went on but it also would have helped me to know what I was going to have to comment on before I got to it. In the beginning I had to go back many times to re-observe for different things.

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<td>Generally clear overall but colour scheme more challenging to interpret the BEA. Communication was fine.</td>
</tr>
<tr>
<td></td>
<td>B</td>
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<tr>
<td></td>
<td>This system seems clearer to me in terms of revealing the individual effort elements.</td>
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<tr>
<td></td>
<td>C</td>
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<tr>
<td></td>
<td>This was the most challenging one to interpret, perhaps because the colours and the overall design seemed to be similar from one to the next. For me it was less clear than the other two systems.</td>
</tr>
<tr>
<td>Overall Comments</td>
<td>This is a fascinating project but challenging for an abstract design to pick up the dynamics including nuances that would be visible in human movement. Straight lines are tricky, lacks the 3-dimensionality of the human body and colours are subjective to the viewer so makes interpreting BEAs in this context a challenge. It was often difficult to observe sustained time especially in system C.</td>
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<td>ID 56</td>
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<td>the dynamics in the light patterns were the most powerful for me, the visual appearance of the swirls/bursts/etc.</td>
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<tr>
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<td>B</td>
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<td>these examples were not as clear for me to ascertain the effort qualities</td>
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<td>C</td>
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<tr>
<td></td>
<td>these examples were also not as clear to me as the first set...</td>
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<td>Overall Comments</td>
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Feedback from incomplete questionnaire

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<td>ID 16</td>
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<td>Visual appearance: colour seems to distinguish elements of phrasing but is sometimes misleading</td>
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<td>No comments on dynamics and clarity, rather: MOVEMENT, which is what this is about:</td>
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|             | On first viewing, I only found visualization that was unmistakable: Mvmt 7 > Vis 5, and I struggled with matching all the others. In the end, it was through a process of elimination that I arrived at my final matching. I found 2.2 much more more useful, since it pointed out to me that I was not perceiving Weight Effort, which made evaluating the
matches for 2.1 a challenge.

How the actions are Phrased presents a problem. The particles seem Indirect before/after the action in general, and the follow through after the action was sometimes hard to discern/separate from the action.

| B | Weight is not present. Space and Time were ambiguous in a few places, for example, Glide had multiple initiation points, so to make it more direct the blue dots can converge more. Vis7 was indiscernible for me: it contains quick initiations but sustained afterwards, starting from one point and radiating outwards - so it is simultaneously sudden/sustained, direct/indirect. Vis6 is also ambiguous - it converges, making it direct, but also accelerates. The acceleration makes it seem like it is "about" Time effort, but it is not sustained or sudden because it actually progresses from sustained to sudden. |

### Participant System / Comment

| ID 26 | A | It was not clear on any parameter - I was just guessing because these visualizations are actually phrases, not actions. I was not sure which portion of the phrase was meant to represent the BEA. |
| B | System B seems more clear than System A re Space and Weight. Time is difficult to perceive because, again, the sequence of color is a phrase. They are only clear in relationship to each other, and even then, one could argue. |

### Participant System / Comment

| ID 43 | A | It was challenging to read for Direct and Indirect Space effort because the colored animations were not as clearly 3-dimensional as the dancer. It was hard to read for weight. I think [I] associate certain colors with more strength. Red looked Stronger. Pastel blue looked Lighter. Purple could go either way. Yellow, Green, and Orange were hard to perceive weight through and I think I inferred and guessed weight on those due to the totality of the visualization. There were some animations that both condensed and spread, so I wasn’t sure which part to focus on. In other words those looked both Direct and Indirect, so I said neither. |

Incomplete

Note. These comments were used in the analysis because they are useful for describing various issues on visualization communicative ability.
B5. Online Participant Consent Statement

LMA Basic-Effort-Actions Validation & EMVIZ Visualization System Evaluation

You are invited to participate in a research survey conducted by Pat Subyen, a Ph.D student at Simon Fraser University, under the guidance of faculty supervisors, Dr. Philippe Pasquier and Dr. Thecla Schiphorst.

As a participant of this study you will help to validate LMA knowledge illustrated through observation and analysis skills. In the survey, you will be asked to complete two tasks described below:

1. Identify the LMA Basic-Effort-Actions:
   In this first task, you will be asked to view 8 short video recordings of a trained CMA and dancer performing one of the Basic-Effort-Actions (BEA) and after each of the 8 shorts clips, associate the video with the name (or name) of that Basic-Effort-Action (BEA). You will be asked to view and identify each of the 8 Basic-Effort-Actions described by Rudolf Laban.

2. Evaluate a set of 8 visualizations (for each of System A, System B and System C) that represent each of the Basic-Effort-Actions (BEA):
   In this task, you will be asked to view visualization sequences generated by data captured from the trained CMA and dancer performing each of the 8 BEAs. You will be asked to match the visualization with the label of its corresponding Basic-Effort-Actions (BEAs), for each of System A, System B, and System C.

The evaluation will take approximately 35 - 40 minutes to complete. You can save your data at any time, and come back to the survey later. Your participation in this study is entirely voluntary. You can discontinue your participation at any time by clicking on the ‘exit and clear survey’ button on the bottom right of the screen and your data will be cleared. You can exit the survey by closing the current web browser and your data will be discarded.

Study Details

Purpose of Research: This study aims to:

1. Validate the consistency and accuracy of the Laban Movement Analysis Effort Framework to codify recognizable movement qualities, specifically the Basic Effort Actions (BEAs).

2. Validate the ability of trained CMA certified Laban Movement Analysts to identify the eight Basic-Effort-Actions (BEAs) in short movement sequences performed by a trained CMA and dancer.

3. Evaluate the communicative ability of three difference versions of the EMVIZ visualization system (System A, System B, and System C) in conveying the 8 Basic Effort Actions in a form of abstract expressive animations or visualizations. Each of the 3 versions of the visualization system use exactly the same input movement data captured from the trained CMA and dancer referred to above in (2).

Your responses to the questions will help us to validate the LMA system and the ability of CMA trained Laban Movement Analysts to recognize and evaluate Effort Qualities. Based on the knowledge of CMA trained experts to recognize the 8 BEAs, your observation and analysis of the different visualization systems will help us to compare and evaluate the communicative efficacy of three different versions of the EMVIZ visualization system. Additionally, your responses to the questions in this survey will help to construct a framework that describes a design process for articulating movement quality visualizations. This includes: an underlying model for capturing and mapping movement qualities to a visualization system, an evaluation methodology, and the ability to communicate information through a participant’s experience.

What you will be asked to:

1. Watch a series of videos that depict movement qualities (BEAs) performed by a dancer and then match the video to one of the 8 Basic Effort Actions (BEAs).

2. Watch a series of videos that depict visual representations of movement quality (BEAs) generated by EMVIZ visualization system based on the movement of the dancer and match the visualization to one of the 8 Basic Effort Actions (BEAs).

Data Being Collected:
Your responses from the online survey will be collected. All data collected will be assigned an anonymous participant code. All the information you supply will be confidential with respect to the SFU Director of Ethics Approval. The data will be stored securely and accessed only by researchers associated with this study.

Questions about the Research:
If you have questions about the research in general, please feel free to contact Pat Subyen either by telephone at 778-394-4905 or by email (p.subyen@sfu.ca). This research project has been reviewed and approved by SFU’s Research Ethics Board and conforms to the standards of the Canadian Tri-Council Research Ethics guidelines. If you want to receive results and publications based upon this experiment, please feel free to contact Pat Subyen via telephone or email provided above.

By Reading the following Consent Statement and Clicking NEXT you are agreeing to the following statements.

I am being asked to participate in a research study on movement quality visualization evaluation. I acknowledge that I have read and understand the information provided above. Understanding that all of the data I provide will be anonymously maintained, analyzed, presented and published. You may proceed by clicking "Next" button. By clicking "Next" button, you have read and understood the participant consent statement and willingly agree, free of coercion, undue influence and consent to participate in this research study. If you decide not to participate, you may close the current web browser.

There are 22 questions in this survey.
Appendix C.

Statistical Analysis Results and Materials

See Chapter 6 folder in Supplemental_Materials.zip

C1. Data Analysis Results for RQ1-RQ3

Data Analysis Raw

1. Frequencies-percentages-results.rtf
2. Match_move rq1 CMH results.rtf
3. CMH-pairwise-match_move.rtf
4. Match_space rq1 CMH results.rtf
5. Match_time rq1 CMH results.rtf
6. Match_weight rq1 CMH results.rtf
7. Pairwise CMH results.rtf
8. Anova_F-test_pairwise results.rtf

- Example of frequencies-percentages-results and match_space q1 CMH results

<table>
<thead>
<tr>
<th>match_move Frequencies (%) by System for Visualization 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>System</td>
</tr>
<tr>
<td>--------</td>
</tr>
<tr>
<td>A</td>
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<tr>
<td>#Participants</td>
</tr>
<tr>
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<td>B</td>
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<td>#Participants</td>
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<td>% of row total</td>
</tr>
<tr>
<td>C</td>
</tr>
<tr>
<td>#Participants</td>
</tr>
<tr>
<td>% of row total</td>
</tr>
<tr>
<td>All Systems</td>
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<tr>
<td>#Participants</td>
</tr>
<tr>
<td>% of row total</td>
</tr>
</tbody>
</table>

Cochran-Mantel_Haenszel Test Results, Plus Frequencies and Percentages by System for Each Visualization

(Alternative Hypothesis that System Mean Scores Differ)

Variable match_space

<table>
<thead>
<tr>
<th>variable</th>
<th>visualization</th>
<th>DF</th>
<th>Value</th>
<th>Prob</th>
</tr>
</thead>
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<td>2</td>
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<tr>
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<td>2</td>
<td>7.0000</td>
<td>0.0302</td>
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<td>0.5134</td>
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<tr>
<td>match_space</td>
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<td>2</td>
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<td>0.8825</td>
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<td>2</td>
<td>7.2000</td>
<td>0.0273</td>
</tr>
<tr>
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<td>2</td>
<td>2.0000</td>
<td>0.2725</td>
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<td>match_space</td>
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<td>5.4286</td>
<td>0.0663</td>
</tr>
<tr>
<td>match_space</td>
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<td>2</td>
<td>5.2500</td>
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</tr>
</tbody>
</table>
C2. Descriptive Statistic Results (Graph & Chart)

C2.1. LMA Validation Results: Task1

The 8 Basic Effort Actions Identification

<table>
<thead>
<tr>
<th>Label (or name) of the BEA</th>
<th>Movement Sequence 1</th>
<th>Movement Sequence 2</th>
<th>Movement Sequence 3</th>
<th>Movement Sequence 4</th>
<th>Movement Sequence 5</th>
<th>Movement Sequence 6</th>
<th>Movement Sequence 7</th>
<th>Movement Sequence 8</th>
</tr>
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<tbody>
<tr>
<td>1. Press</td>
<td>12, 100%</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>2. Punch</td>
<td></td>
<td>12, 100%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>3. Wring</td>
<td></td>
<td></td>
<td>12, 100%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Dab</td>
<td></td>
<td></td>
<td></td>
<td>12, 100%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Flick</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>12, 100%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Float</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>12, 100%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Glide</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>12, 100%</td>
<td></td>
</tr>
<tr>
<td>8. Slash</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>12, 100%</td>
</tr>
</tbody>
</table>
C2.2. LMA Validation Results: Task2

The 8 Basic Effort Actions Order Identification
C2.3. EMVIZ Evaluation Results

C2.3.1. System A (Task1): The eight Basic-Effort-Actions identification

The majority of participants tended to incorrectly identify Punch as Slash (66.7%), Dab as Punch (58.3%), Slash as Flick (75%), and Flick as Dab (58.3%).
Some participants tended to incorrectly identify Wring as Glide (25%) or Press (41.57%) and Press as Wring (50%), while other visualizations (i.e., Punch, Dab, Slash, Flick, Glide, and Float) were diffusively mismatched with various movement sequences (e.g., Dab as Slash [8.3%], Flick [25%], Glide [8.3%] or Wring [8.3%]).
C2.3.3. System C (Task1): The eight Basic-Effort-Actions identification

The majority of participants tended to mismatch visualizations with various movement sequences (e.g., Dab as Punch [8.3%], Slash [33.3%], and Flick [33.3%]).
The Effort parameter values identification results for system A was as follows:

- The average percentage\(^1\) of correct identification of all three Effort parameter values for Punch visualization is 50%. The results suggest failure of communicative ability for Direct Space (0%), marginal performance for Strong Weight (50%), and excellent performance for Sudden Time (100%).

- The average percentage of correct identification of all three Effort parameter values for Dab visualization is 55.6%. The results suggest marginal communicative ability for Direct Space (50%), failure for Light Weight (16.7%), and excellent performance for Sudden Time (100%).

- The average percentage of correct identification of all three Effort parameter values for Slash visualization is 55.6%. The results suggest marginal communicative ability for Indirect Space (58.3%), failure for Strong Weight (16.7%), and excellent performance for Sudden Time (91.7%).

- The average percentage of correct identification of all three Effort parameter values for Flick visualization is 55.5%. The results suggest failure of communicative ability for Indirect Space (33.3%), marginal performance for Strong Weight (58.3%), and good performance for Sudden Time (75%).

- The average percentage of correct identification of all three Effort parameter values for Glide visualization is 72.2%. The results suggest marginal communicative ability for Direct Space (50%), satisfactory performance for Strong Weight (66.7%), and excellent performance for Sustained Time (100%).

- The average percentage of correct identification of all three Effort parameter values for Wring visualization is 72.2%. The results suggest marginal

\(^1\) The average percentage of correctly identified Effort parameter values for each visualization was calculated based on the total number of correctly identified Effort parameter values divided by 3 (i.e., the number of parameter values of each visualization). There are three Effort parameter values for each Basic-Effort-Actions visualization: Space, Weight, Time. Space is either Direct or Indirect. Weight is either Strong or Light. Time is either Sudden or Sudden.
communicative ability for Indirect Space (50%), satisfactory performance for Strong Weight (66.7%), and excellent performance for Sustained Time (100%).

- The average percentage of correct identification of all three Effort parameter values for Press visualization is 55.6%. The results suggest marginal communicative ability for Indirect Space (50%) and Strong Weight (50%), and satisfactory performance for Sustained Time (66.7%).

- The average percentage of correct identification of all three Effort parameter values for Float visualization is 72.2%. The results suggest marginal communicative ability for Indirect Space (58.3%) and Light Weight (58.3%), and excellent performance for Sustained Time (100%).

C2.3.5. System B: Effort parameter values precision (Task2)

The Effort parameter values identification results for system B was as follows:

- The average percentage of correct identification of all three Effort parameter values for Punch visualization is 58.3%. The results suggest failure of communicative ability for Direct Space (33.3%), marginal performance for Strong Weight (50%), and excellent performance for Sudden Time (91.7%).

- The average percentage of correct identification of all three Effort parameter values for Dab visualization is 52.8%. The results suggest failure of communicative ability for Direct Space (16.7%), good performance for Light Weight (75%), and satisfactory performance for Sudden Time (66.7%).

- The average percentage of correct identification of all three Effort parameter values for Slash visualization is 69.4%. The results suggest marginal communicative ability for Indirect Space (58.3%), satisfactory performance for Strong Weight (66.7%), and good performance for Sudden Time (83.3%).

- The average percentage of correct identification of all three Effort parameter values for Flick visualization is 58.3%. The results suggest failure of communicative ability for Indirect Space (41.7%), marginal performance for Strong Weight (50%), and good performance for Sudden Time (83.3%).

- The average percentage of correct identification of all three Effort parameter values for Glide visualization is 69.4%. The results suggest marginal
communicative ability for Direct Space (50%), satisfactory performance for Strong Weight (66.7%), and excellent performance for Sustained Time (91.7%).

- The average percentage of correct identification of all three Effort parameter values for Wring visualization is 41.7%. The results suggest failure of communicative ability for Indirect Space (16.7%), marginal performance for Strong Weight (50%), and satisfactory performance for Sustained Time (66.7%).

- The average percentage of correct identification of all three Effort parameter values for Press visualization is 38.9%. The results suggest failure of communicative ability for Indirect Space (25%) and Strong Weight (41.7%), and marginal performance for Sustained Time (50%).

- The average percentage of correct identification of all three Effort parameter values for Float visualization is 72.2%. The results suggest good communicative ability for Indirect Space (75%) and Strong Weight (83.3%), and marginal performance for Sustained Time (58.3%).

C2.3.6. System C: Effort parameter values precision (Task2)

![Effort parameter values precision chart](chart.jpg)

The Effort parameter values identification results for system C was as follows:

- The average percentage of correct identification of all three Effort parameter values for Punch visualization is 55.5%. The results suggest failure of communicative ability for Direct Space (33.3%), marginal performance for Strong Weight (50%), and good performance for Sudden Time (83.3%).

- The average percentage of correct identification of all three Effort parameter values for Dab visualization is 38.9%. The results suggest failure of communicative ability for Direct Space (8.3%) and Light Weight (16.7%), and excellent performance for Sudden Time (91.7%).

- The average percentage of correct identification of all three Effort parameter values for Slash visualization is 63.9%. The results suggest failure of communicative ability for Strong Weight (33.3%), good communicative ability for Indirect Space (75%), and good performance for Sudden Time (83.3%).

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• The average percentage of correct identification of all three Effort parameter values for Flick visualization is 50%. The results suggest failure of communicative ability for Indirect Space (41.7%) and Strong Weight (25%), and good performance for Sudden Time (83.3%).

• The average percentage of correct identification of all three Effort parameter values for Glide visualization is 41.6%. The results suggest failure of communicative ability for Direct Space (0%), marginal performance for Strong Weight (58.3%), and satisfactory performance for Sustained Time (66.7%).

• The average percentage of correct identification of all three Effort parameter values for Wring visualization is 41.6%. The results suggest failure of communicative ability for Indirect Space (41.7%) and Strong Weight (25%), and marginal performance for Sustained Time (58.3%).

• The average percentage of correct identification of all three Effort parameter values for Press visualization is 33.3%. The results suggest failure of communicative ability for Indirect Space (8.3%) and Strong Weight (33.3%), and marginal performance for Sustained Time (58.3%).

• The average percentage of correct identification of all three Effort parameter values for Float visualization is 38.9%. The results suggest failure of communicative ability for Indirect Space (33.3%) and Strong Weight (33.3%), and marginal performance for Sustained Time (50%).
C2.3.7. System A (Task2): Effort parameter values identification

**SYSTEM A : EMVIZ (Motion-Agent)**

<table>
<thead>
<tr>
<th>Visualization</th>
<th>Direct Effort Parameter Values</th>
<th>Indirect Effort Parameter Values</th>
<th>Neither Effort Parameter Values</th>
<th>Direct Effort Parameter Values</th>
<th>Indirect Effort Parameter Values</th>
<th>Neither Effort Parameter Values</th>
<th>Direct Effort Parameter Values</th>
<th>Indirect Effort Parameter Values</th>
<th>Neither Effort Parameter Values</th>
<th>Correct Effort Parameter Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visualization1 (Punch)</td>
<td>10.0%</td>
<td>8.3%</td>
<td>1.9%</td>
<td>10.0%</td>
<td>8.3%</td>
<td>1.9%</td>
<td>10.0%</td>
<td>8.3%</td>
<td>1.9%</td>
<td>100%</td>
</tr>
<tr>
<td>Visualization2 (Dab)</td>
<td>5.5%</td>
<td>3.2%</td>
<td>2.6%</td>
<td>5.5%</td>
<td>3.2%</td>
<td>2.6%</td>
<td>5.5%</td>
<td>3.2%</td>
<td>2.6%</td>
<td>100%</td>
</tr>
<tr>
<td>Visualization3 (Slash)</td>
<td>2.1%</td>
<td>1.6%</td>
<td>3.8%</td>
<td>2.1%</td>
<td>1.6%</td>
<td>3.8%</td>
<td>2.1%</td>
<td>1.6%</td>
<td>3.8%</td>
<td>100%</td>
</tr>
<tr>
<td>Visualization4 (Flick)</td>
<td>4.3%</td>
<td>2.3%</td>
<td>1.3%</td>
<td>4.3%</td>
<td>2.3%</td>
<td>1.3%</td>
<td>4.3%</td>
<td>2.3%</td>
<td>1.3%</td>
<td>100%</td>
</tr>
<tr>
<td>Visualization5 (Glide)</td>
<td>0.0%</td>
<td>3.2%</td>
<td>2.6%</td>
<td>0.0%</td>
<td>3.2%</td>
<td>2.6%</td>
<td>0.0%</td>
<td>3.2%</td>
<td>2.6%</td>
<td>100%</td>
</tr>
<tr>
<td>Visualization6 (Wing)</td>
<td>4.3%</td>
<td>2.3%</td>
<td>1.3%</td>
<td>4.3%</td>
<td>2.3%</td>
<td>1.3%</td>
<td>4.3%</td>
<td>2.3%</td>
<td>1.3%</td>
<td>100%</td>
</tr>
<tr>
<td>Visualization7 (Press)</td>
<td>0.0%</td>
<td>3.2%</td>
<td>2.6%</td>
<td>0.0%</td>
<td>3.2%</td>
<td>2.6%</td>
<td>0.0%</td>
<td>3.2%</td>
<td>2.6%</td>
<td>100%</td>
</tr>
<tr>
<td>Visualization8 (Float)</td>
<td>2.9%</td>
<td>1.3%</td>
<td>1.3%</td>
<td>2.9%</td>
<td>1.3%</td>
<td>1.3%</td>
<td>2.9%</td>
<td>1.3%</td>
<td>1.3%</td>
<td>100%</td>
</tr>
</tbody>
</table>

**Effort Factors Accuracy**
- Space: 44.8%
- Weight: 46.9%
- Time: 88.6%

**Effort Parameter Values Accuracy**
- Direct: 37.5%
- Indirect: 52%
- Strong: 43.7%
- Light: 50%
- Sudden: 91.7%
- Sustained: 88.5%

**Average Effort Accuracy**: 60.1%
C2.3.8. System B (Task 2): Effort parameter values identification

**SYSTEM B : EMVIZ (Sketch)**

<table>
<thead>
<tr>
<th>Visualization</th>
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<th>WEIGHT</th>
<th>TIME</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td>Indirect</td>
<td>Neither</td>
</tr>
<tr>
<td>Visualization 1 (Punch)</td>
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<td>1.83%</td>
<td>7.58%</td>
</tr>
<tr>
<td>Visualization 2 (Dab)</td>
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<td>5.41%</td>
<td>5.41%</td>
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<tr>
<td>Visualization 3 (Slash)</td>
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<td>Visualization 4 (Flick)</td>
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<td>4.33%</td>
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<tr>
<td>Visualization 5 (Glide)</td>
<td>6.50%</td>
<td>5.41%</td>
<td>1.83%</td>
</tr>
<tr>
<td>Visualization 6 (Wing)</td>
<td>1.83%</td>
<td>2.16%</td>
<td>3.25%</td>
</tr>
<tr>
<td>Visualization 7 (Press)</td>
<td>3.25%</td>
<td>6.50%</td>
<td>5.41%</td>
</tr>
<tr>
<td>Visualization 8 (Float)</td>
<td>1.83%</td>
<td>9.75%</td>
<td>2.16%</td>
</tr>
</tbody>
</table>

Effort Factors Accuracy: SPACE 39.6% WEIGHT 59.4% TIME 74%
Effort Parameter Values Accuracy: Direct 31.3% Indirect 47.9% Strong 50% Light 68.8% Sudden 81.3% Sustained 66.7%

Average 57.7%
C2.3.9. System C (Task2): Effort parameter values identification

**SYSTEM C : EMVIZ (L)**

<table>
<thead>
<tr>
<th>Visualization</th>
<th>Direct</th>
<th>Indirect</th>
<th>Neither</th>
<th>Strong</th>
<th>Light</th>
<th>Neither</th>
<th>Sudden</th>
<th>Sustained</th>
<th>Neither</th>
</tr>
</thead>
<tbody>
<tr>
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<td>4, 33.3%</td>
<td>4, 33.3%</td>
<td>6, 50%</td>
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<td>10, 91.7%</td>
<td>1, 8.3%</td>
<td>1, 8.3%</td>
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<tr>
<td>Visualization2 (Dab)</td>
<td>5, 7.8%</td>
<td>5, 41.7%</td>
<td>6, 50%</td>
<td>2, 25%</td>
<td>2, 16.7%</td>
<td>10, 83.3%</td>
<td>1, 8.3%</td>
<td>1, 8.3%</td>
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</tr>
<tr>
<td>Visualization3 (Slash)</td>
<td>1, 8.3%</td>
<td>0, 66.7%</td>
<td>4, 33.3%</td>
<td>2, 16.7%</td>
<td>2, 25%</td>
<td>10, 83.3%</td>
<td>2, 16.7%</td>
<td>1, 8.3%</td>
<td>1, 8.3%</td>
</tr>
<tr>
<td>Visualization4 (Flick)</td>
<td>0, 6, 33.3%</td>
<td>4, 33.3%</td>
<td>2, 16.7%</td>
<td>7, 58.3%</td>
<td>3, 25%</td>
<td>6, 66.7%</td>
<td>1, 8.3%</td>
<td>1, 8.3%</td>
<td></td>
</tr>
<tr>
<td>Visualization5 (Glide)</td>
<td>3, 25%</td>
<td>5, 41.7%</td>
<td>2, 16.7%</td>
<td>7, 58.3%</td>
<td>3, 25%</td>
<td>6, 66.7%</td>
<td>1, 8.3%</td>
<td>1, 8.3%</td>
<td></td>
</tr>
<tr>
<td>Visualization6 (Wiring)</td>
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<td>5, 41.7%</td>
<td>2, 16.7%</td>
<td>7, 58.3%</td>
<td>3, 25%</td>
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<td>1, 8.3%</td>
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</tr>
<tr>
<td>Visualization7 (Press)</td>
<td>1, 8.3%</td>
<td>5, 41.7%</td>
<td>2, 16.7%</td>
<td>7, 58.3%</td>
<td>3, 25%</td>
<td>6, 66.7%</td>
<td>1, 8.3%</td>
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<tr>
<td>Visualization8 (Float)</td>
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<td>7, 58.3%</td>
<td>3, 25%</td>
<td>6, 66.7%</td>
<td>1, 8.3%</td>
<td>1, 8.3%</td>
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</tbody>
</table>

**Effort Factors Accuracy**
- Direct 12.5% Indirect 29.2% Strong 35.4% Light 33.3% Sudden 83.3% Sustained 58.3%

**Average 42.4%**
C2.3.10. The average percentage of correctly identified Effort parameter values among systems

The Effort parameter values identification results for system A are as follows:

- For the Space Effort parameter, the average percentage for correct identification of Direct Space is 37.5%, while the majority of participants tended to incorrectly identify Direct as Indirect (41.7%) and neither (20.85%) for Punch, Dab, Glide, and Press visualizations. The average percentage for correct identification of Indirect Space is 52%, while participants incorrectly identified Indirect as Direct (27%) and neither (20.8%) for Slash, Flick, Wring, and Float visualizations.

- For the Weight Effort parameter, the average percentage for correct identification of Strong Weight is 43.7%, while participants incorrectly identified Strong as Light (27.1%) and neither (29.2%) for Punch, Slash, Wring, and Press visualizations. The average percentage for correct identification of Light Weight is 50%, while participants incorrectly identified Light as Strong (8.3%) and neither (33.3%) for Dab, Flick, Glide, and Float visualizations.

- For the Time Effort parameter, the average percentage for correct identification of Sudden Time is 91.7%, while a few participants incorrectly identified Sudden as Sustained (16.7%) for Punch, Dab, Slash, and Flick visualizations. The average percentage for correct identification of Sustained Time is 85.5%, while participants incorrectly identified Sustained as Sudden (25%) and neither (8.3%) for Glide, Wring, Press, and Float visualizations.

The Effort parameter values identification results for system B are as follows:
• For the Space Effort parameter, the average percentage for correct identification of Direct Space is 31.3%, while the majority of participants tended to incorrectly identify Direct as Indirect (35.4%) and neither (33.3%) for Punch, Dab, Glide, and Press visualizations. The average percentage for correct identification of Indirect Space is 47.9%, while participants incorrectly identified Indirect as Direct (22.9%) and neither (28.4%) for Slash, Flick, Wring, and Float visualizations.

• For the Weight Effort parameter, the average percentage for correct identification of Strong Weight is 50%, while participants incorrectly identified Strong as Light (20.8%) and neither (29.2%) for Punch, Slash, Wring, and Press visualizations. The average percentage for correct identification of Light Weight is 68.8%, while participants incorrectly identified Light as Strong (8.3%) and neither (22.9%) for Dab, Flick, Glide, and Float visualizations.

• For the Time Effort parameter, the average percentage for correct identification of Sudden Time is 81.3%, while a few participants incorrectly identified Sudden as Sustained (8.3%) and neither (10.4%) for Punch, Dab, Slash, and Flick visualizations. The average percentage for correct identification of Sustained Time is 66.7%, while participants incorrectly identified Sustained as Sudden (14.6%) and neither (18.8%) for Glide, Wring, Press, and Float visualizations.

The Effort parameter values identification results for system C are as follows:

• For the Space Effort parameter, the average percentage for correct identification of Direct Space is 12.5%, while the majority of participants tended to incorrectly identify Direct as Indirect (48%) and neither (39.6%) for Punch, Dab, Glide, and Press visualizations. The average percentage for correct identification of Indirect Space is 29.2%, while participants incorrectly identified Indirect as Direct (27%) and neither (43.8%) for Slash, Flick, Wring, and Float visualizations.

• For the Weight Effort parameter, the average percentage for correct identification of Strong Weight is 35.4%, while participants incorrectly identified Strong as Light (18.8%) and neither (45.9%) for Punch, Slash, Wring, and Press visualizations. The average percentage for correct identification of Light Weight is 33.3%, while participants incorrectly identified Light as Strong (18.8%) and neither (47.9%) for Dab, Flick, Glide, and Float visualizations.

• For the Time Effort parameter, the average percentage for correct identification of Sudden Time is 85.4%, while a few participants incorrectly identified Sudden as Sustained (4.15%) and neither (10.4%) for Punch, Dab, Slash, and Flick visualizations. The average percentage for correct identification of Sustained Time is 58.3%, while participants incorrectly identified Sustained as Sudden (25%) and neither (16.7%) for Glide, Wring, Press, and Float visualizations.

For Direct Space, system A has the greatest communicative ability (37.5%), followed by system B (31.3%) and system C (12.5%). For Indirect Space, system A has the greatest communicative ability (52%), followed by system B (47.9%) and system C (29.2%). For Strong Weight, system B has the greatest communicative ability (50%), followed by system A (43.7%) and system C (35.4%). For Light Weight, system B has the greatest communicative ability (68.8%), followed by system A (50%) and system C (33.3%). For
Sudden Time, system A has the greatest communicative ability (91.7%), followed by system C (85.4%) and system B (81.3%). For Sustained Time, system A has the greatest communicative ability (85.5%), followed by system B (66.7%) and system C (58.3%).

C3. Inferential Statistic Results (Descriptive)

C3.1. RQ1 CMH pairwise comparisons

<table>
<thead>
<tr>
<th>Visualization</th>
<th>Comparison Between Systems</th>
<th>DF</th>
<th>Value</th>
<th>Prob</th>
</tr>
</thead>
<tbody>
<tr>
<td>Punch</td>
<td>A versus B</td>
<td>1</td>
<td>7.0000</td>
<td>0.0082</td>
</tr>
<tr>
<td></td>
<td>A versus C</td>
<td>1</td>
<td>3.5714</td>
<td>0.0588</td>
</tr>
<tr>
<td></td>
<td>B versus C</td>
<td>1</td>
<td>1.0000</td>
<td>0.3173</td>
</tr>
<tr>
<td>Slash</td>
<td>A versus B</td>
<td>1</td>
<td>5.4444</td>
<td>0.0196</td>
</tr>
<tr>
<td></td>
<td>A versus C</td>
<td>1</td>
<td>3.0000</td>
<td>0.0833</td>
</tr>
<tr>
<td></td>
<td>B versus C</td>
<td>1</td>
<td>2.6667</td>
<td>0.1025</td>
</tr>
<tr>
<td>Flick</td>
<td>A versus B</td>
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<td>6.0000</td>
<td>0.0143</td>
</tr>
<tr>
<td></td>
<td>A versus C</td>
<td>1</td>
<td>3.0000</td>
<td>0.0833</td>
</tr>
<tr>
<td></td>
<td>B versus C</td>
<td>1</td>
<td>1.8000</td>
<td>0.1797</td>
</tr>
<tr>
<td>Glide</td>
<td>A versus B</td>
<td>1</td>
<td>1.8000</td>
<td>0.1797</td>
</tr>
<tr>
<td></td>
<td>A versus C</td>
<td>1</td>
<td>6.4000</td>
<td>0.0114</td>
</tr>
<tr>
<td></td>
<td>B versus C</td>
<td>1</td>
<td>5.0000</td>
<td>0.0253</td>
</tr>
<tr>
<td>Wring</td>
<td>A versus B</td>
<td>1</td>
<td>8.0000</td>
<td>0.0047</td>
</tr>
<tr>
<td></td>
<td>A versus C</td>
<td>1</td>
<td>3.5714</td>
<td>0.0588</td>
</tr>
<tr>
<td></td>
<td>B versus C</td>
<td>1</td>
<td>1.8000</td>
<td>0.1797</td>
</tr>
</tbody>
</table>

Note: The significant results are highlighted in grey. A = EMVIZ (Motion-Agent), B = EMVIZ (Sketch), and C = EMVIZ (L).

- There is a difference in the percentage of correctly matched Punch movement with Punch visualization between systems A and B with respect to p-value = 0.0082, where system B had 83.3% correct matches and system A had 25% correct matches (Fig. 6.2). Thus, system B’s communicative ability for Punch visualization performs better than system A. The difference between systems A and C was nearly significant (p = 0.0588). However, there is no difference between systems B and C (p = 0.3173).

- There is a difference in the percentage of correctly matched Slash movement with Slash visualization between systems A and B with respect to p-value = 0.0196, where system B had 66.7% correctly matched and system A had 8.3% correctly matched. Thus, system B’s communicative ability for Slash visualization performs better than system A.

- There is a difference in the percentage of correctly matched Flick movement with Flick visualization between systems A and B with respect to p-value = 0.0143, where system B had 50% correctly matched and system A had 0% correctly matched. Thus, system B’s communicative ability for Flick visualization performs better than system A.
• There is a difference in the percentage of correctly matched Glide movement with Glide visualization between systems A and C with respect to p-value = 0.0114, where system A had 91.7% correctly matched and system C had 25% correctly matched. There is also a difference between systems B and C with respect to p-value = 0.0253, where system B had 66.7% correctly matched and system C had 25% correctly matched. Thus, the communicative ability of both systems A and B for Glide visualization perform better than system C.

• There is a difference in the percentage of correctly matched Wring movement with Wring visualization between systems A and B with respect to p-value = 0.0047, where system A had 83.3% correctly matched and system B had 16.7% correctly matched. Thus, system A’s communicative ability for Wring visualization performs better than system B. The difference between systems A and C was nearly significant (p = 0.0588).

C3.2. RQ2 CMH pairwise comparisons

C3.2.1. SPACE

<table>
<thead>
<tr>
<th>BEA Visualization</th>
<th>SPACE Effort Comparison</th>
<th>DF</th>
<th>Value</th>
<th>Prob</th>
</tr>
</thead>
<tbody>
<tr>
<td>Punch</td>
<td>A versus B</td>
<td>1</td>
<td>4.0000</td>
<td>0.0455</td>
</tr>
<tr>
<td></td>
<td>A versus C</td>
<td>1</td>
<td>4.0000</td>
<td>0.0455</td>
</tr>
<tr>
<td></td>
<td>B versus C</td>
<td>1</td>
<td>0.0000</td>
<td>1.0000</td>
</tr>
<tr>
<td>Dab</td>
<td>A versus B</td>
<td>1</td>
<td>4.0000</td>
<td>0.0455</td>
</tr>
<tr>
<td></td>
<td>A versus C</td>
<td>1</td>
<td>5.0000</td>
<td>0.0253</td>
</tr>
<tr>
<td></td>
<td>B versus C</td>
<td>1</td>
<td>0.3333</td>
<td>0.5637</td>
</tr>
<tr>
<td>Glide</td>
<td>A versus B</td>
<td>1</td>
<td>0.0000</td>
<td>1.0000</td>
</tr>
<tr>
<td></td>
<td>A versus C</td>
<td>1</td>
<td>6.0000</td>
<td>0.0143</td>
</tr>
<tr>
<td></td>
<td>B versus C</td>
<td>1</td>
<td>6.0000</td>
<td>0.0143</td>
</tr>
</tbody>
</table>

The results of CMH pairwise comparisons for Space Effort parameter values are summarized as follows:

• There is a difference in the percentage of correctly identified Space Effort parameter values for Punch visualization between systems A and B and systems A and C with respect to p-value = 0.0455, where system A had 0% and systems B and C had 33.3% correctly identified Direct Space (Fig. 6.3). Thus, the communicative ability of Space Effort for systems B and C are considerably better than system A.

• There is a difference in the percentage of correctly identified Space Effort parameter values for Dab visualization between systems A and B with respect to p-value = 0.0455 and systems A and C with respect to p-value = 0.0253, where system A had 50%, system B had 16.7%, and system C had 8.3% correctly identified Direct Space (Fig. 6.3). Thus, the communicative ability of Dab Space Effort for system A is better than for systems B and C.
There is a difference in the percentage of correctly identified Space Effort parameter values for Glide visualization between systems A and B and systems B and C with respect to p-value = 0.0143, where system A had 66.7%, B had 66.7%, and C had 58.3% correctly identified Indirect Space (Fig. 6.3). Thus, the communicative ability of Space Effort for systems A and B are better than system C.

C3.2.2. WEIGHT

<table>
<thead>
<tr>
<th>BEA Visualization</th>
<th>WEIGHT Effort Comparison</th>
<th>DF</th>
<th>Value</th>
<th>Prob</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dab</td>
<td>A versus B</td>
<td>1</td>
<td>5.4444</td>
<td>0.0196</td>
</tr>
<tr>
<td></td>
<td>A versus C</td>
<td>1</td>
<td>0.0000</td>
<td>1.0000</td>
</tr>
<tr>
<td></td>
<td>B versus C</td>
<td>1</td>
<td>7.0000</td>
<td>0.0082</td>
</tr>
<tr>
<td>Slash</td>
<td>A versus B</td>
<td>1</td>
<td>4.5000</td>
<td>0.0339</td>
</tr>
<tr>
<td></td>
<td>A versus C</td>
<td>1</td>
<td>1.0000</td>
<td>0.3173</td>
</tr>
<tr>
<td></td>
<td>B versus C</td>
<td>1</td>
<td>4.0000</td>
<td>0.0455</td>
</tr>
<tr>
<td>Float</td>
<td>A versus B</td>
<td>1</td>
<td>1.8000</td>
<td>0.1797</td>
</tr>
<tr>
<td></td>
<td>A versus C</td>
<td>1</td>
<td>1.8000</td>
<td>0.1797</td>
</tr>
<tr>
<td></td>
<td>B versus C</td>
<td>1</td>
<td>6.0000</td>
<td>0.0143</td>
</tr>
</tbody>
</table>

The results of CMH pairwise comparisons for Weight Effort parameter values are summarized as follows:

- There is a difference in the percentage of correctly identified Weight Effort parameter values for Dab visualization between systems A and B with respect to p-value = 0.0196 and systems B and C with respect to p-value = 0.0082. Systems A, B, and C had 16.7%, 75%, and 16.7% correctly identified Light Weight, respectively (Fig. 6.3). Thus, the communicative ability of Weight Effort for system B is better than for systems A and C.

- There is a difference in the percentage of correctly identified Weight Effort parameter values for Slash visualization between systems A and B with respect to p-value = 0.0399 and systems B and C with respect to p-value = 0.0455. Systems A, B, and C had 16.7%, 66.7%, and 33.3% correctly identified Strong Weight, respectively (Fig. 6.3). Thus, the communicative ability of Weight Effort for system B is better than system C, followed by system A.

- There is a difference in the percentage of correctly identified Weight Effort parameter values for Float visualization between systems B and C with respect to p-value = 0.0143, where system B had 83.3% and system C had 33.3% correctly identified Light Weight (Fig. 6.3). Thus, the communicative ability of Weight Effort for system B is better than system C.
C3.2.3. TIME

<table>
<thead>
<tr>
<th>BEA Visualization</th>
<th>TIME Effort Comparison</th>
<th>DF</th>
<th>Value</th>
<th>Prob</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dab</td>
<td>A versus B</td>
<td>1</td>
<td>4.0000</td>
<td>0.0455</td>
</tr>
<tr>
<td></td>
<td>A versus C</td>
<td>1</td>
<td>1.0000</td>
<td>0.3173</td>
</tr>
<tr>
<td></td>
<td>B versus C</td>
<td>1</td>
<td>3.0000</td>
<td>0.0833</td>
</tr>
<tr>
<td>Glide</td>
<td>A versus B</td>
<td>1</td>
<td>1.0000</td>
<td>0.3173</td>
</tr>
<tr>
<td></td>
<td>A versus C</td>
<td>1</td>
<td>4.0000</td>
<td>0.0455</td>
</tr>
<tr>
<td></td>
<td>B versus C</td>
<td>1</td>
<td>3.0000</td>
<td>0.0833</td>
</tr>
<tr>
<td>Wring</td>
<td>A versus B</td>
<td>1</td>
<td>4.0000</td>
<td>0.0455</td>
</tr>
<tr>
<td></td>
<td>A versus C</td>
<td>1</td>
<td>5.0000</td>
<td>0.0253</td>
</tr>
<tr>
<td></td>
<td>B versus C</td>
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<td>0.2000</td>
<td>0.6547</td>
</tr>
<tr>
<td>Float</td>
<td>A versus B</td>
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<td>5.0000</td>
<td>0.0253</td>
</tr>
<tr>
<td></td>
<td>A versus C</td>
<td>1</td>
<td>6.0000</td>
<td>0.0143</td>
</tr>
<tr>
<td></td>
<td>B versus C</td>
<td>1</td>
<td>0.2000</td>
<td>0.6547</td>
</tr>
</tbody>
</table>

The results of CMH pairwise comparisons for Time Effort parameter values are summarized as follows:

- There is a difference in the percentage of correctly identified Time Effort parameter values for Dab visualization between systems A and B with respect to p-value = 0.0455, where system A had 100% and system B had 66.7% correctly identified Sudden Time (Fig. 6.3). Thus, the communicative ability of Time Effort for system A is significantly better than system B.

- There is a difference in the percentage of correctly identified Time Effort parameter values for Glide visualization between systems A and C with respect to p-value = 0.0455, where system A had 100% and system C had 66.7% correctly identified Sustained Time (Fig. 6.3). Thus, the communicative ability of Time Effort for system A is significantly better than system C.

- There is a difference in the percentage of correctly identified Time Effort parameter values for Wring visualization between systems A and B with respect to p-value = 0.0455, and systems A and C with respect to p-value = 0.0253, where systems A, B, and C had 100%, 66.7%, and 58.3% correctly identified Sustained Time, respectively (Fig. 6.3). Thus, the communicative ability of Time Effort for system A is better than for systems B and C.

- There is a difference in the percentage of correctly identified Time Effort parameter values for Float visualization between systems A and B with respect to p-value = 0.0253 and systems A and C with respect to p-value = 0.0143, where systems A, B, and C had 100%, 58.3%, and 50% correctly identified Sustained Time, respectively (Fig. 6.3). Thus, the communicative ability of Time Effort for system A is better than for systems B and C.
C4. **Likelihood Ratio (LR): Test for Equality of Variances among Systems**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>ProbF</th>
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</thead>
<tbody>
<tr>
<td>Match</td>
<td>0.98963</td>
</tr>
<tr>
<td>Space</td>
<td>0.83539</td>
</tr>
<tr>
<td>Weight</td>
<td>0.58029</td>
</tr>
<tr>
<td>Time</td>
<td>0.00932</td>
</tr>
</tbody>
</table>

Note: This test is performed according to assumption required for analysis of variances. Significance implies difference among variances. In such cases, the model is refitted with unequal variances.

C5. **Feedback on three EMVIZ systems**

The open-ended survey questions analyzed were:

**Question 2.3, 3.3, and 4.3, you have just viewed visual representations of the eight Basic Effort Actions generated by EMVIZ (A, B, C). Please write down your responses regarding the effectiveness of System A, B, and C’s ability to communicate the eight Basic Effort Actions through the following: visual appearance, colour, dynamics, and clarity of communication.**

Content analysis technique\(^2\) was applied to segment similar answers among systems. First, for each EMVIZ system, each participant’s feedback was categorized and grouped together (see Fig. C-1 (a)). Second, the analysis diagram used for categorizing and grouping participant feedback data was created (See Fig. C-A (b), in order to see the connections among systems.

**See Analytical Results in Chapter 6 folder in Supplemental_Materials.zip**

- Example of feedback analysis

---

\(^2\) Content analysis is “any technique for making inferences by systematically and objectively identifying special characteristics of messages” (Holsti 1968, p.608 cite from Berg 2001). See: Berg, B.L. (2007). Qualitative research methods for the social sciences, Pearson/Allyn & Bacon.
**Figure C-1 Feedback analysis: grouping, categorization, and analysis diagram**
Appendix D.

Comparative Analysis (Descriptive)

D1. Eight Levels of Analysis

D1.1. SPACE: Shape, Texture, Direction, and Motion Path Curvature

D1.1.1. Shape

Shape refers to the areas that define an object in space, such as point, line, and plane. A plane is a flat surface with length and breadth and it can be classified as geometric, organic, rectilinear, irregular, and hand-drawn (Hann, 2012; Wong, 1975). Geometric plane is a shape that can be constructed mathematically (e.g., rectangle, triangle or circle), while organic, rectilinear, irregular, and hand-drawn shapes cannot be constructed mathematically and are considered abstract shapes. Shape can be either single or overall. Single shape refers to one shape while overall shape refers to a new shape or object that emerges from multiple shapes. According to affective motion texture research, Lockyer et al. and Feng use the term motion texture instead of overall shape. Motion texture can be circular, spherical, radial, spiral or linear and they can elicit different affective impressions (Lockyer et al., 2011; Feng, 2014). My analysis employs various types of motion textures and defines them as overall shape, which can be represented as circular, radial, spiral, linear, and abstract. In this case, overall abstract shape refers to the merging of multiple shapes that cannot be readily identified.

![Figure D-1. Examples of the overall shape of visualization. From left to right: linear, radial, spherical, spiral, and abstract motion pattern.](Image generated from Motionscapes software prototype (Feng, 2014).

D1.1.2. Texture

In general, texture is one of the basic visual elements and refers to the surface property or surface characteristics of a shape (Carpendale, 2001; Wong, 1968). In this comparative analysis, I use the term "texture" when referring to visual texture, a surface property of two-dimensional shape perceived by the eye. Texture was chosen as one unit of analysis and categorized in association with Space Effort because it has a close relationship with shape and it can convey the perceived properties of visual texture or aesthetic property, such as rough, warm, elegant, natural, sophisticated, simple or modern (Thumfart et al., 2011). These properties can be used to describe different
perceptions among three visualization styles generated by the three EMVIZ systems. Texture has two values: with texture and without texture.

D1.1.3. Direction

In static visual composition, orientation refers to the changes in alignment of shapes or objects and it suggests the direction of shapes or objects in the space. In moving visual composition, direction refers to where the shapes or objects are moving towards in the space. Direction can vary from left, right, upward, downward, upward-left, downward-left, upward-right, downward-right, and centre, and it can be either towards or outwards, such as towards the centre, outwards from the centre, towards upward-left or outwards from right. In the LMA Effort concepts of diagonal scale and Effort affinities, direction was used to describe Effort parameter values bounded between two extremes. For instance, Light is upward, Strong is downward, Sudden is forward, Sustained is backward, Direct is rightward (opening), and Indirect is leftward (closing). However, this analysis associated direction with Space Effort rather than Weight and Time because, in computer generated motion, objects that move upward, downward, forward or backward are not ideal for representing or conveying a sense of Weight and Time Effort. Space Effort, however, is more suitable for associating with direction because Direct or Indirect Space can be easily identified by observing an object's direction and trace of motion in the space.

D1.1.4. Motion Path Curvature

In moving visual composition or computer animation, motion path curvature refers to the trajectories of moving objects or trace of motion of the object as it progresses in the space. Motion path curvature can be defined as straight, arch, angular, wavy or meandering (Lockyer et al., 2012; Tagiuri, 1960, cited from Nakatani, 2009). Straight motion path curvature refers to the directness of trace of motion, while arch motion path curvature refers to the curviness of trace of motion as it progresses. Angular motion path curvature refers to motion path that has sharp corners or jerkiness. Wavy motion path curvature refers to a series of undulating and wavelike curves, while meandering path curvature refers to the indirectness of motion that appears to wander aimlessly. In this analysis, I use the term “curve” when referring to arch and wavy motion. Thus motion path curvature values are straight, curve, angular, meandering or random. Random, in this case, refers to trace of motion or motion path curvature that has more than two values. Motion path curvature is an important visual variable for Space Effort identification because, in combination with overall shape and direction, it can convey directness or indirectness of the motion.

D1.2. WEIGHT: Size and Colour

D1.2.1. Size

From a scientific perspective, the human nervous system and human perception tend to perceive weight and size according to prior experience, which creates size bias to weight perception and weight bias to the size perception of objects (Hirsiger et al., 2012). For instance, big objects tend to look heavier than small objects, while small objects tend to look lighter than big objects. In LMA Effort, Weight qualities may indicate sensibility and intention towards an action such as Light (delicate or sensitive) and Strong (firm, solid,
and forceful) (Maletic, 2005). In art and design, size is an important visual element, which refers to the width and height of the area occupied by shape. Changing the size perception of objects in association with other visual properties (e.g., texture or colour saturation) can convey a sense of weight because in the real world, we tend to combine weight and size cues according to our prior experience. In comparative analysis, size variable has two values: increase and decrease.

D1.2.2. Colour

In Bertin’s seven visual variables, he considers value as the changes of shades of grey (i.e., from lightness to darkness) and uses the term “colour” when referring to the changes in hue without changes in colour value (Carpendale, 2003). In this analysis, I use the term “colour” when referring to hue, saturation, and value variables. Hue of colour refers to colour pureness, saturation is colour whiteness, and value is colour darkness. Each of these variables has three values: fix, increase, and decrease. According to colour psychology, the darker or more saturated a colour is, the more it connotes “forcefulness,” while the more hue a colour has, the more it connotes “calmness” (Wright & Rainwater, 1962). Thus using a specific hue (i.e., red) in combination with changing colour variables (i.e., saturation and value) can convey a sense of weight.

D1.3. TIME Effort and Visual variables: Speed and Acceleration

Speed and Acceleration

Speed and acceleration are fundamental properties of human movement and traditional animation. In LMA Time Effort, the quality of movement is bounded between Sudden and Sustained and they may indicate an intuitive readiness for decision making (Maletic, 2005). High movement activity or high speed and acceleration of body movement can create a sense of excitement or arouse multiple emotions, while low movement dynamics can create a sense of sadness or low intensity (Atkinson et al., 2004). High amplitude, speed, and fluidity of movement can convey distinct emotions (i.e., angry, excited, strong or happy) and this type of movement is also significantly associated with greater acceleration and deceleration (Pollick et al., 2001). This knowledge is also linked with the fundamental principles of traditional animation theory, where speed is often associated with the weight and the size of the object or the force exerted on the object (Bacigalupi, 1998 and Lassiter, 1987 cited from Nakatani, 2009). Thus, I associate Time Effort factor with speed and acceleration variables. In this analysis, speed and acceleration values are fast, slow, increase, and decrease, respectively.

D2. Visualization Observation

All visualization used in the observation process can be found here:

- EMVIZ (L) https://vimeo.com/album/2993947
- EMVIZ (Sketch) https://vimeo.com/album/2993962
- EMVIZ (Motion-Agent) https://vimeo.com/album/2914594
D3. A Brief Summary of Similarities and Differences of three EMVIZ Systems

The similarities and differences of design strategy of three EMVIZ systems\(^3\) are divided into three categories (i.e., Space, Weight, and Time) and summarized as follows:

D3.1. SPACE

First, all eight Basic-Effort-Actions visualizations generated by systems A and C used the same shape and visual properties (i.e., rectangle with fill colour and line with stroke colour), but system B used two shapes with various visual properties (i.e., circle with fill colour and stroke weight, and line with stroke colour). These shapes and visual properties of the three EMVIZ systems were generated using different computation techniques (i.e., system A = boids system or flocking algorithm, system B = eight different computations, and system C = L-system; see Chapter 4, section 4.4). Thus the output visualizations of the three EMVIZ systems have a different look and feel from each other. The overall shape of visualization generated by all systems was abstract. System C visualizations were the most complex and abstract, followed by systems A and B. Some visualization generated by systems A and B resembled linear, radial or spiral shapes but the overall look and feel were abstract. System A used a custom design texture mapped onto shape surface, while systems B and C did not use texture. Thus system A visualizations had a more natural, simple, modern, and smooth feel than systems B and C because system A could convey a perceived property of a visual texture. For overall visual appearance, systems A and C had more sense of oneness or design unity than system B because all visualizations (i.e., the eight Basic-Effort-Actions) used the same shape and computation to generate visualization. System B, on the other hand, used eight different computations (i.e., one computation per each Basic-Effort-Action visualization), resulting in eight different visualization styles.

Second, all visualizations generated by systems A and B used a similar design strategy to represent Space Effort (i.e., various directions of the motion patterns), but system C used only one strategy to represent Space Effort (i.e., randomly move outwards from centre to all directions). The motion path curvature of systems A and C was straight and curved, and straight and angular, respectively. System B’s motion path curvature, on the other hand, was mixed among three types: straight, curved, and meandering. For instance, Punch, Dab, Flick, Glide, and Float visualizations have straight motion path curvature, while Slash and Wring visualizations have straight and curve motion path curvature. This is because systems A and C used computations (i.e., flocking algorithm and L-system) that have less control on output visualization than system B.\(^4\) This means system B has more control on visual output generation and motion path curvature can be precisely programmed, while the visual output of systems A and C were randomly generated because of the nature of computation used for generating visualization.

---

\(^3\) EMVIZ (Motion-Agent) = system A; EMVIZ (Sketch) = system B; EMVIZ (L) = system C

D3.2. WEIGHT

Systems A and B used similar colour mapping design strategies, wherein eight colour schemes were assigned to the eight Basic-Effort-Actions with fixed colour properties (i.e., hue, saturation, and colour value). Colour saturation, size of the shape, and stroke weight increased according to the values of a stream of Basic-Effort-Action vectors data (i.e., high values = high colour saturation), except for system B’s Flick visualization where the diameter of the circle increased, decreased, and dissolved from the screen. System C, on the other hand, used a different colour mapping design strategy, in which six colour palettes were assigned to six Effort parameter values (i.e., Direct, Indirect, Strong, Light, Sudden, and Sustained) with fixed colour properties. Thus, each Basic-Effort-Action visualization was composed of three colour palettes. For instance, Punch visualization colour was composed of Direct, Strong, and Sudden colour palettes. However, system C’s colour saturation was fixed and did not change according to the values of a stream of Basic-Effort-Actions vectors data.

D3.3. TIME

All systems used similar design strategies to represent Time Effort. System A and some of system B’s Basic-Effort-Action visualizations used fixed speed and acceleration values. For system A, the default speed and acceleration of Sudden movement was set with high value and Sustained movement was set with low value. The speed and acceleration of visual animation changed according to the values of a stream of Basic-Effort-Actions vectors. For Sudden movement, speed and acceleration increased; for Sustained movement, speed and acceleration also increased but just slightly in order to maintain a sense of Sustained motion. System B used the same design strategy as system A for Slash and Wring visualizations and used fixed speed with no acceleration for Punch, Dab, Glide, Press, and Float visualizations. For Flick visualization, speed and acceleration increased according to the values of a stream of Basic-Effort-Actions vectors data, and then decreased and dissolved from the screen. System C, on the other hand, used fixed speed value with no acceleration for all visualizations because of the nature of L-system algorithm (i.e., there is no need to use acceleration for generating visualization).
## D4. Microanalysis (Descriptive)

### D4.1. Press

<table>
<thead>
<tr>
<th>Effort Parameter Values</th>
<th>Visual Variables</th>
<th>System A</th>
<th>System B</th>
<th>System C</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Shape</strong> Single</td>
<td>Velocity Point (fill)</td>
<td>Line</td>
<td>Line</td>
<td>Line</td>
</tr>
<tr>
<td><strong>Shape</strong> Overall</td>
<td>Velocity Point (fill)</td>
<td>Line</td>
<td>Line</td>
<td>Line</td>
</tr>
<tr>
<td><strong>Texture</strong></td>
<td>With Texture</td>
<td>Without Texture</td>
<td>Without Texture</td>
<td>Without Texture</td>
</tr>
<tr>
<td><strong>Direction</strong></td>
<td>Move towards centre and randomly move outwards from centre</td>
<td>Randomly move Outwards from centre to all directions</td>
<td>Randomly move Outwards from centre to all directions</td>
<td></td>
</tr>
<tr>
<td><strong>Motion Path Curvature</strong></td>
<td>Straight and Curve</td>
<td>Straight and Curve</td>
<td>Straight and Angular</td>
<td></td>
</tr>
<tr>
<td><strong>Size</strong></td>
<td>Increase size</td>
<td>Increase circle diameter</td>
<td>Increase stroke weight &amp; line length</td>
<td></td>
</tr>
<tr>
<td><strong>Colour</strong> H: Fix hue</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S: Increase saturation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>V: Fix value</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Speed</strong></td>
<td>Slow</td>
<td>Slow (Fix)</td>
<td>Slow (Fix)</td>
<td></td>
</tr>
<tr>
<td><strong>Acceleration</strong></td>
<td>Increase (a little)</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

Note: A = EMIVZ (Motion-Agent), B = EMIVZ (Sketch), C = EMIVZ (L)

For system A, the “moving towards centre” motion (i.e., unpredictable motion patterns caused by the nature of boids system or flocking algorithm) could not convey a sense of Press because of the quickness and weightless motion. For systems A and B, curve motion path curvature could make the overall shape of visualization look Indirect instead of Direct. This problem was reflected by a marginal or low percentage of correctly identified Direct Space parameter (i.e., system A = 50% and system B = 25%). Strong Weight Effort was not well communicated because changing object size and colour saturation were not clearly represented. Additionally, the purple colour scheme could be perceived as Strong or Light. This problem was reflected by a marginal or low percentage of correctly identified Strong Weight (systems A and B = 41.7%). Time Effort was not well communicated because of (1) the abstractness of overall shape of visualization (for systems A and B) and (2) the multiple Effort parameter values presented in visualization (for system A). Although system A had some problems communicating three Effort parameter values, it successfully conveyed a sense of Press quality, with 75% correctly identified Press visualization. However, these problems affected system B, where the percentage of correctly identified Press visualization was 33.3% (see Appendix C, section 2.3.7 - 2.38).
Unlike systems A and B, system C’s main problem was the complexity of overall shape of visualization caused by the L-system (i.e., abstractness and quickness of visualization). This problem affected all Basic-Effort-Actions visualization and system C failed to communicate Press Effort (i.e., 41.7%) and its parameter values (i.e., Direct [8.3%], Strong [33.3%], and Sustained [58.3%]; See Appendix C, section 2.3.9). Direct Space Effort was hard to perceive because the overall abstractness made motion path curvature look Indirect instead of Direct and the colour’s lightness could not convey a sense of Strong Weight Effort.

From these results, it appeared that system A’s design strategy performed better than systems B and C. However, we cannot conclude that system A’s design strategy is the best for representing Press quality (Direct, Strong, and Sustained) because there is no significant difference in correctly identified Press visualization and its Effort parameter values for all three EMVIZ systems (see Chapter 6, Table 6.10).

**D4.2. Glide**

<table>
<thead>
<tr>
<th>Effort Parameter Values</th>
<th>Visual Variables</th>
<th>System A</th>
<th>System B</th>
<th>System C</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Shape</strong> (Single)</td>
<td>Rectangle (fil)</td>
<td></td>
<td>Circle (fi)</td>
<td>Line</td>
</tr>
<tr>
<td><strong>Shape</strong> (Overall)</td>
<td>Resemble linear shape - Abstract</td>
<td></td>
<td>Resemble linear shape - Abstract</td>
<td>Unidentified - Abstract</td>
</tr>
<tr>
<td><strong>Texture</strong></td>
<td>With Texture</td>
<td></td>
<td>Without Texture</td>
<td>Without Texture</td>
</tr>
<tr>
<td><strong>Direction</strong></td>
<td>Move upward-right and right</td>
<td></td>
<td>Each shape appears from a random position and moves upward-right and right</td>
<td>Randomly move outwards from centre to all directions</td>
</tr>
<tr>
<td><strong>Motion Path Curvature</strong></td>
<td>Straight and Curve</td>
<td></td>
<td>Straight</td>
<td>Straight and Angular</td>
</tr>
<tr>
<td><strong>Size</strong></td>
<td>Increase size</td>
<td></td>
<td>Increase circle diameter</td>
<td>Increase stroke weight &amp; line length</td>
</tr>
<tr>
<td><strong>Colour</strong></td>
<td>H: Fix hue</td>
<td></td>
<td>H: Fix hue</td>
<td>H: Fix hue</td>
</tr>
<tr>
<td></td>
<td>S: Increase saturation</td>
<td>S: Increase saturation</td>
<td>S: Fix saturation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>V: Fix value</td>
<td></td>
<td>V: Fix value</td>
<td>V: Fix value</td>
</tr>
<tr>
<td><strong>Time</strong></td>
<td>Slow</td>
<td></td>
<td>Slow (Fix)</td>
<td>Slow (Fix)</td>
</tr>
<tr>
<td><strong>Acceleration</strong></td>
<td>Increase (a little)</td>
<td></td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

Note: A = EMIVZ (Motion-Agent), B = EMIVZ (Sketch), C = EMIVZ (L)

For system A, the “moving upward right or toward right” direction with curve motion path curvature could make the overall shape of visualization appear abstract and Indirect instead of Direct. This issue was reflected by a marginal percentage of correctly identified Space Effort parameter (i.e., Direct [50%]; see Appendix C, section 2.3.7). For system B, the way each shape faded in from a random position could create a sense of
multiple foci (i.e., Indirect), contradicting Effort parameter values of Glide visualization (i.e., Direct). Although each shape moved upward right or right direction with a straight motion path curvature, the overall shape of visualization resembled non-linear motion pattern. This made the overall shape of visualization appear more abstract than intended. This issue was reflected by a marginal percentage of correctly identified Space Effort parameter (i.e., Direct [50%]; see Appendix C, section 2.3.8).

For systems A and B, Light Weight Effort was satisfactorily communicated (i.e., A and B = [66.7%]). Weight Effort communication could be improved if the changing size of the object and colour saturation were clearly represented. Time Effort was excellently communicated (i.e., A = [100%] and B = [91.7%]). System B’s Time Effort communication could be improved by using an acceleration parameter as a function of time for generating visualization. The average percentage of correctly identified Glide visualization for systems A and B was 91.7% and 66.7% respectively (see Appendix C, section 2.3.1 - 2.3.2).

System C completely failed to communicate Space Effort (i.e., 0%) because of the abstractness of overall shape of visualization caused by the nature of L-system computation. Weight Effort was fairly communicated (i.e., 58.3%) because the overall colour (i.e., light blue) appeared to convey lightness. Weight Effort communication could be improved if colour saturation was used as one colour function to represent Light Weight Effort. Sustained Time Effort was satisfactorily communicated (i.e., 66.7%) but this might be coincidental as participants likely matched Sustained Time Effort with colour (i.e., light blue) because light colour can convey a sense of calmness (i.e., Sustained movement; [Wright & Rainwater 1962]). These problems caused the low percentage of correctly identified Glide visualization (i.e., 25%; see Appendix C, section 2.3.3).

These results appear to suggest that system A’s design strategy is better than systems B and C. However, we cannot conclude that system A’s design strategy is the best, followed by systems B and C, because there is a significant difference in correctly identified Glide visualization wherein systems A and B performed better than system C. This means that the design strategies of systems A and B equally communicated Glide Effort and both systems performed better than system C. There was also a significant difference in correctly identified Space and Time Effort. For Space Effort, systems A and B performed better than system C. For Time Effort, system A performed better than system C. This means the Space Effort design strategies of systems A and B equally communicated and performed better than system C. In terms of Time Effort design strategy, system A performed better than system C (see Chapter 6, Table 6.10).
D4.3. Punch

<table>
<thead>
<tr>
<th>Effort Parameter Values</th>
<th>Visual Variables</th>
<th>System A</th>
<th>System B</th>
<th>System C</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Shape</strong> (Single)</td>
<td>Rectangle (fill)</td>
<td>Circle (fill)</td>
<td>Line</td>
<td></td>
</tr>
<tr>
<td><strong>Shape</strong> (Overall)</td>
<td>Resemble radial &amp; abstract shape</td>
<td>Blurry bubble-like shape - Abstract</td>
<td>Unidentified - Abstract</td>
<td></td>
</tr>
<tr>
<td><strong>Texture</strong></td>
<td>With Texture</td>
<td>Without Texture</td>
<td>Without Texture</td>
<td></td>
</tr>
<tr>
<td><strong>Direction</strong></td>
<td>Burst out from centre and move towards centre</td>
<td>Burst out from centre to all directions</td>
<td>Randomly move outward from centre to all directions</td>
<td></td>
</tr>
<tr>
<td><strong>Motion Path Curvature</strong></td>
<td>Straight and Curve</td>
<td>Straight</td>
<td>Straight and Angular</td>
<td></td>
</tr>
<tr>
<td><strong>Size</strong></td>
<td>Increase size</td>
<td>Increase circle diameter</td>
<td>Increase stroke weight &amp; line length</td>
<td></td>
</tr>
<tr>
<td><strong>Colour</strong> H: Fix hue</td>
<td>S: Increase saturation</td>
<td>V: Fix value</td>
<td>H: Fix hue</td>
<td>S: Increase saturation</td>
</tr>
<tr>
<td><strong>TIME</strong> Speed F: Fast</td>
<td>Acceleration Increase</td>
<td>–</td>
<td>F: Fast (fix)</td>
<td>–</td>
</tr>
</tbody>
</table>

Note: A = EMIVZ (Motion-Agent), B = EMIVZ (Sketch), C = EMIVZ (L)

For system A, the “bursting out from centre” motion direction (i.e., unpredictable motion patterns caused by the nature of boids system or flocking algorithm) could create a sense of Indirect instead of Direct because of (1) multiple foci in visualization (i.e., each shape moves outswards from centre), (2) a curve path curvature, and (3) the abstractness of overall shape of visualization. These issues are reflected by a failure percentage of correctly identified Space Effort (i.e., Direct [0%]). This problem also caused more than half of participants (i.e., 58.3%) to identify Punch as Slash (see Chapter 6, Table 6.3). Weight Effort was not well communicated because the change of shape size and colour saturation were not clearly represented (i.e., Strong 50%). However, the red colour scheme is appropriate for representing Strong Weight because (1) it can convey a sense of excitement and connotes “forcefulness” according to colour psychology (Wright & Rainwater 1962) and (2) some participants (ID 35 and 43) reported that the red colour was helpful in indicating strength. Time Effort was excellently communicated (i.e., 100%). Taken altogether, the percentage of correctly identified Punch visualization was 25%. From these results, Space Effort appeared to be a major problem for communicating Punch quality.

For system B, the “bursting out from centre to all directions” motion direction could create a sense of multiple foci or Indirect Effort instead of Direct Effort. Although the motion path curvature was straight, it could not convey a sense of Direct Effort. This issue was reflected by a low percentage of correctly identified Direct Space Effort.
parameter (i.e., 33%). For Weight Effort, the changing size of the shape and increasing colour saturation were clearly represented. However, Strong Weight Effort was not well communicated (i.e., 50% identification). Sudden Time Effort was very well communicated (i.e., 91.7%). Although Space and Weight Effort had some issues, the average percentage of correctly identified Punch visualization was 83.3%. This is likely because the overall look and feel of the visualization was simple and not too complex (i.e., bubble-like shape), although the overall shape of visualization was abstract.

In system C, the angular and straight motion path curvature and visual complexity caused the overall shape of visualization to look abstract and Indirect instead of Direct. This issue was reflected by a low percentage of correctly identified Space Effort parameter (i.e., Direct [33%]). It also affected Strong Weight Effort perception. Although participants used colour as a reference for identifying Weight Effort, the overall visualization did not convey a sense of Strong Weight Effort. This assumption was supported by the participant feedback described in Chapter 6 section 6.4.3. For instance, ID11 said, “I interpreted Weight factor with more primary colo[u]rs for Strong Weight and more pale colo[u]rs for Light Weight, but it seemed a little arbitrary because the visualization itself didn’t really give me a sense of Weight through the movement of the image.” This issue was reflected by a marginal percentage of correctly identified Weight Effort parameter (i.e., Strong [50%]). Time Effort had good communication (i.e., 83.3%). Although Space and Weight Effort had some issues, the percentage of correctly identified Punch visualization was fairly communicated (i.e., 66.7%).

These results indicate that system B’s design strategy performed better than systems A and C. However, we cannot conclude that system B’s design strategy is the best for representing Punch quality because there is a significant difference in correctly identified Punch visualization wherein system B performed better than system A (see Chapter 6, Table 6.10). This means that systems B and C equally communicated Punch quality, as did systems A and C. Additionally, there is no significant difference in correctly identified Weight and Time Effort but there is a significant difference for Space Effort, as systems B and C performed better than system A. Thus the three systems equally communicated Weight and Time Effort, while systems B and C equally communicated Space Effort. However, the percentage of correctly identified Space Effort for both systems was low (33.3%). Thus, we cannot conclude that the design strategies of systems B and C are the best for communicating Space Effort.
D4.4. Dab

<table>
<thead>
<tr>
<th>Effort Parameter Values</th>
<th>Visual Variables</th>
<th>System A</th>
<th>System B</th>
<th>System C</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Shape</strong> (Single)</td>
<td><img src="image" alt="Rectangle (fill)" /></td>
<td><img src="image" alt="Circle (no fill)" /></td>
<td><img src="image" alt="Line" /></td>
<td></td>
</tr>
<tr>
<td><strong>Shape</strong> (Overall)</td>
<td><img src="image" alt="Unidentified - Abstract" /></td>
<td><img src="image" alt="Multiple circular shapes - Abstract" /></td>
<td><img src="image" alt="Unidentified - Abstract" /></td>
<td></td>
</tr>
<tr>
<td><strong>Texture</strong></td>
<td>With Texture</td>
<td>Without Texture</td>
<td>Without Texture</td>
<td></td>
</tr>
<tr>
<td><strong>Direction</strong></td>
<td>Move towards centre and move outwards from centre</td>
<td>Randomly appear and move outwards from centre</td>
<td>Randomly move outward from centre to all directions</td>
<td></td>
</tr>
<tr>
<td><strong>Motion Path Curvature</strong></td>
<td><img src="image" alt="Straight and Curve" /></td>
<td><img src="image" alt="Straight" /></td>
<td><img src="image" alt="Straight and Angular" /></td>
<td></td>
</tr>
<tr>
<td><strong>Size</strong></td>
<td><img src="image" alt="Increase size" /></td>
<td><img src="image" alt="Increase circle diameter &amp; stroke weight" /></td>
<td><img src="image" alt="Increase stroke weight &amp; line length" /></td>
<td></td>
</tr>
<tr>
<td><strong>Colour</strong></td>
<td>H: Fix hue</td>
<td>H: Fix hue</td>
<td>H: Fix hue</td>
<td></td>
</tr>
<tr>
<td></td>
<td>S: Increase saturation</td>
<td>S: Increase saturation</td>
<td>S: Fix saturation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>V: Fix value</td>
<td>V: Fix value</td>
<td>V: Fix value</td>
<td></td>
</tr>
<tr>
<td><strong>Speed</strong></td>
<td>Fast</td>
<td>Fast (fix)</td>
<td>Fast (fix)</td>
<td></td>
</tr>
<tr>
<td><strong>Acceleration</strong></td>
<td>Increase</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
</tbody>
</table>

Note: A = EMIVZ (Motion-Agent), B = EMIVZ (Sketch), C = EMIVZ (L)

For system A, the “moving towards centre” motion (i.e., unpredictable motion patterns caused by the nature of boids system or flocking algorithm) created a sense of Indirect Effort instead of Direct Effort because of the curviness of motion path curvature. Weight Effort failed to communicate lightness because (1) the colour was highly saturated and (2) the magenta colour scheme could be perceived as Strong or Light depending on colour saturation and colour value. These issues were reflected by a marginal or very low percentage of correctly identified Space and Weight Effort parameter (i.e., Direct [50%] and Light [16.7%]; see Appendix C, section 2.3.7). In contrast, Time Effort was excellently communicated (i.e., 100%). Taken altogether, the average percentage of correctly identified Dab visualization was 16.7% (see Appendix C, section 2.3.1). From these results, Weight Effort seemed to be a major problem for communicating Dab quality.

For system B, the random appearance of each shape could create a sense of multiple foci or Indirect instead of Direct, although the “moving outwards from centre” motion direction with straight motion path curvature could convey a sense of Direct. This is probably because multiple shapes appeared on the screen. This issue was reflected by a very low percentage of correctly identified Direct Space Effort (i.e., 16.7%; see Appendix C, section 2.3.8). Light Weight Effort was well communicated because the increasing stroke weight and circle diameter and the colour lightness were clearly represented (i.e., 75%). Sudden Time Effort was fairly communicated (i.e., 66.7%)
because the transition speed of animation (i.e., fade in and fade out) was somewhat between Sudden and Sustained. Taken altogether, the average percentage of correctly identified Dab visualization was 50% (see Appendix C, section 2.3.2).

Similarly to other Basic-Effort-Action visualizations, system C’s major issues were Space and Weight Effort communication according to the very low percentage of correctly identified Direct Space and Light Weight Effort (i.e., 8.3% and 16.7%; see Appendix C, section 2.3.9). This is because the overall visualization looked very abstract and there were multiple colours used in the Dab colour palette. Sudden Time Effort was well communicated (i.e., 91.7%) but the animation speed looked less natural because of the overall quickness of visualization. Taken altogether, the average percentage of correctly identified Dab visualization was 25% (see Appendix C, section 2.3.3).

From these results, it seems that system B’s design strategy performed better than systems A and C. However, we cannot conclude that system B’s design strategy is the best for representing Dab quality because there is no significant difference in correctly identified Dab visualization among the three EMVIZ systems (see Chapter 6, Table 6.10). This means that Dab quality was equally communicated. However, there is a significant difference among systems in correctly identified Space, Weight, and Time Effort parameter values. For Space Effort, system A performed better than systems B and C. For Weight Effort, system B performed better than systems A and C. For Time Effort, system A performed better than system B. This means that systems A and C and systems B and C equally communicated Sudden Time Effort.
In the beginning of system A’s visualization sequence, the “spiral motion towards centre with curve” motion path curvature conveyed a sense of Indirect. However, in the end of the visualization sequence, the “moving outwards from centre” direction with a straight motion path curvature created a sense of Direct Effort instead of Indirect Effort. Thus there were multiple Effort parameter values presented in the visualization (i.e., Direct and Indirect). This problem was reflected by (1) a marginal percentage of correctly identified Indirect Space Effort (i.e., 50%) and (2) the participant feedback report, in which several participants reported that they had a hard time identifying Effort parameter values because some visualization contained two Effort parameter values (see Chapter 6, section 6.4). Although the blue-purple colour scheme could be perceived as Strong or Light depending on participants’ cultural background, Light Weight Effort was fairly communicated (i.e., 66.7%). Time Effort had the same problem as Space Effort, in which Sustained and Sudden Time Effort appeared at the beginning and end of the visualization sequence. However, Time Effort was excellently communicated (i.e., 100%) and the average percentage of correctly identified Wring visualization was 83.3% (see Appendix C, section 2.3.1 and 2.3.7). From these results, Space Effort seemed to be a major problem for communicating Wring quality.

In the beginning of system B’s visualization sequence, the “moving towards centre” direction with a meandering motion path curvature created a sense of Direct Effort instead of Indirect Effort. At the end of the visualization sequence, the “moving outwards
from centre" direction with a straight motion path curvature also created a sense of Direct Effort instead of Indirect Effort. Thus system B’s design strategy completely failed to communicate Space Effort because the percentage of correctly identified Indirect Effort was 16.7%. For Time Effort, similarly to system A, Sustained Time Effort appeared in the beginning of the visualization sequence, while Sudden Time Effort appeared at the end of the sequence. Thus there were multiple Effort parameter values presented in the visualization (i.e., Sustained and Sudden). This issue was reflected by a fair percentage of correctly identified Sustained Time Effort (66.7%). Strong Weight Effort was not well communicated (i.e., 41.7%) because blue or purple colours can convey a sense of Strong or Light depending on colour intensity and colour value. These problems caused a very low percentage of correctly identified Wring visualization (i.e., 16.7%; see Appendix C, section 2.3.2 and 2.3.8).

System C’s major problems involved communication of three Effort parameter values, according to the low percentage of correctly identified Indirect Space (41.7%) and Strong Weight (25%). This is because the overall shape of visualization looked very abstract and there were multiple colours used in the Wring colour palette. Thus the colour scheme (i.e., green mixed with red) could not represent Wring visualization. Although Time Effort was fairly communicated (58.3%), the speed of animation was somewhat between Sudden and Sustained. These problems caused the low average percentage of correctly identified Wring visualization (i.e., 41.7%; see Appendix C, section 2.3.3 and 2.3.9).

From these results, it seems that system A’s design strategy is the best for representing Wring quality, followed by systems C and B, respectively. However, we cannot conclude that system A’s design strategy is the best for representing Wring quality because there is a significant difference in correctly identified Wring visualization wherein system A performed better than system B. There is no significant difference between system A and C, as well as systems B and C (see Chapter 6, Table 6.10). This means systems A and C equally communicated Wring quality, as did systems B and C. Additionally, there is a significant difference among systems in correctly identified Time Effort parameter—but not for Space and Weight Effort—and system A performed better than systems B and C.
D4.6. Float

For system A, the straight motion path curvature caused by the flocking algorithm created a sense of Direct Effort instead of Indirect Effort. Light Weight Effort was fairly communicated because green, light-green, and lime green colours are considered cold or warm and they could be perceived as Strong or Light depending on colour intensity. These issues were reflected by a fair percentage of correctly identified Space and Weight Effort (i.e., Direct [58.3%] and Light [58.3%]). Time Effort was excellently communicated (i.e., 100%). The average percentage of correctly identified Float visualization was 83.3% (see Appendix C, section 2.3.1 and 2.3.7).

For system B, the straight motion path curvature and the lightness of green, light-green, and lime green colours successfully conveyed a sense of Direct and Light Effort, evidenced by a good percentage of correctly identified Space and Weight Effort parameter values (i.e., Indirect [75%] and Light [83.3%]). This is probably because (1) each shape randomly appeared in different locations, creating multiple foci (i.e., a sense of Indirect Effort) in the overall visualization and (2) the colour intensity and colour value were light enough to eliminate the warmness in green, light-green, and lime green. However, Time Effort was not well communicated (i.e., 58.3%), possibly because (1) system B used a fixed animation speed that could eliminate “liveness” in motion and (2) the animation speed was somewhat between quick and slow. These issues were reflected by 25% of participants selecting neither Sudden nor Sustained Time Effort in part 2 of the survey study. Although there were some problems in system B, the
percentage of correctly identified Float visualization was 75% (see Appendix C, section 2.3.2 and 2.3.8).

Similarly to other Basic-Effort-Actions visualizations, system C had problems in Space, Weight, and Time Effort communication. The Space and Weight Effort could not convey a sense of Indirect Effort (i.e., 33%) and Light Effort (i.e., 33%) because (1) the overall shape of visualization looked very abstract and (2) the colour scheme was composed of multiple colours. Time Effort was marginally communicated (i.e., 50%) because the animation speed were somewhat between quick and slow. These problems were reflected by a low percentage of correctly identified Float visualization (i.e., 41.7%; see Appendix C, section 2.3.3 and 2.3.9).

From these results, it appeared that system A’s design strategy performed better than systems B and C. However, we cannot conclude that system A’s design strategy is the best for representing Float quality (Direct, Strong, and Sustained) because there is no significant difference in correctly identified Float visualization among all three systems (see Chapter 6, Table 6.10). However, there is a significant difference among the systems in correctly identified Weight and Time Effort parameters for Float visualization. For Weight Effort, system B performed better than system C. This means that systems A and B equally communicated Light Weight Effort, as did systems A and C. For Time Effort, system A performed better than systems B and C. This means that system A’s design strategy is the best for representing Time Effort.
## D4.7. Slash

<table>
<thead>
<tr>
<th>Effort Parameter Values</th>
<th>Visual Variables</th>
<th>System A</th>
<th>System B</th>
<th>System C</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Shape</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Single)</td>
<td>Rectangle (fill)</td>
<td></td>
<td>Line</td>
<td>Line</td>
</tr>
<tr>
<td>(Overall)</td>
<td>Unidentified - Abstract</td>
<td>Sometimes look radial - Abstract</td>
<td>Unidentified - Abstract</td>
<td></td>
</tr>
<tr>
<td><strong>Texture</strong></td>
<td>With Texture</td>
<td>Without Texture</td>
<td>Without Texture</td>
<td></td>
</tr>
<tr>
<td><strong>Direction</strong></td>
<td>Randomly moving outwards from centre to all directions</td>
<td>Moving towards centre and move outwards from centre to all directions</td>
<td>Randomly move outwards from centre to all directions</td>
<td></td>
</tr>
<tr>
<td><strong>Motion Path Curvature</strong></td>
<td>Straight and Curve</td>
<td>Straight and Curve</td>
<td>Straight and Angular</td>
<td></td>
</tr>
<tr>
<td><strong>Size</strong></td>
<td>Increase size</td>
<td>Increase stroke weight</td>
<td>Increase stroke weight &amp; line length</td>
<td></td>
</tr>
<tr>
<td><strong>Colour</strong></td>
<td>H: Fix hue</td>
<td>H: Fix hue</td>
<td>H: Fix hue</td>
<td></td>
</tr>
<tr>
<td></td>
<td>S: Increase saturation</td>
<td>S: Increase saturation</td>
<td>S: Fix saturation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>V: Fix value</td>
<td>V: Fix value</td>
<td>V: Fix value</td>
<td></td>
</tr>
<tr>
<td><strong>Speed</strong></td>
<td>Fast</td>
<td>Fast</td>
<td>Slow (Fix)</td>
<td></td>
</tr>
<tr>
<td><strong>Acceleration</strong></td>
<td>Increase</td>
<td>Increase</td>
<td>Increase</td>
<td></td>
</tr>
</tbody>
</table>

Note: A = EMIVZ (Motion-Agent), B = EMIVZ (Sketch), C = EMIVZ (L)

For system A, the “randomly moving outwards from centre to all directions” with the straight and curve motion path curvatures could convey a sense of Indirect Effort. However, some participants may have been unable to perceive this type of motion as Direct or Indirect because of the overall abstractness of visualization caused by the flocking algorithm. For Weight Effort, some colours in the Slash colour palette have a low colour intensity and colour value that can convey a sense of Light Effort instead of Strong Effort. Additionally, the changing size of the shape was not clearly represented. These problems were reflected by a fair percentage of correctly identified Indirect Space and Strong Weight Effort (i.e., 58.3%) and about 25% of participants could not identify Space and Weight Effort (i.e., selected neither Direct nor Indirect and neither Strong nor Light in task 2 of the questionnaire). Time Effort had a good percentage of correctly identified Sudden Time Effort (i.e., 91.7%). Taken altogether, the identified problems caused a fail percentage of correctly identified Slash Effort (i.e., 8.3%; see Appendix C, section 2.3.1 and 2.3.7).

System B used the same design strategy as system A; however, the output visualization contained undesired motion pattern (i.e., moving towards centre direction). In the beginning of the visualization, each shape (i.e., line) moves towards the centre and, in the middle and at end of the visualization, each shape moves outwards from the centre with straight and curve motion path curvatures. This caused some participants to perceive Space Effort as simultaneously Direct and Indirect. This assumption is
supported by participant feedback, wherein 41.7% of participants failed to identify Space Effort (i.e., selected neither Direct nor Indirect in task 2 of the questionnaire). However, Indirect Space Effort was fairly communicated (i.e., 58.3%). This is probably because the overall visualization did not look too abstract. For Weight Effort, as with system A, changing stroke weight and colour saturation were not clearly represented because the colour intensity and stroke weight (i.e., orange scheme) were too low and too thin to convey a sense Strong Weight Effort. However, Strong Weight Effort was fairly communicated (i.e., 66.7%). Time Effort was communicated to a good degree (i.e., 83.3%). Taken altogether, the percentage of correctly identified Slash Effort was fairly communicated (i.e., 66.7%; see Appendix C, section 2.3.2 and 2.3.8).

System C’s major problem seems to be Space and Weight Effort communication because of the overall abstractness of visualization and the multiple colours used in colour palette. These problems were reflected by no correct identification of Indirect Space Effort (i.e., 0%) and only approximately 33.3% correctly identified Strong Weight Effort. However, Time Effort was well communicated (i.e., 83.3%). Space and Weight Effort problems were reflected by a low percentage of correctly identified Slash visualization (i.e., 33.3%; see Appendix C, section 2.3.3 and 2.3.9).

These results suggest that system B’s design strategy is the best for representing Slash visualization because it performed better than systems A and C. However, we cannot conclude this because there is a significant difference in correctly identified Slash visualization and system B performed better than A. This means systems B and C equally communicated Slash visualization, as did systems A and C. For communication of three Effort factors (Space, Weight, and Time), there was also a significant difference among systems in correctly identified Weight Effort for Slash visualization but not for Space and Time Effort and system B performed better than systems A and C. This means that system B has the best design strategy for representing Light Weight Effort.
In the beginning of system A’s visualization sequence, the “moving towards upward-left” motion direction caused difficulty in Space Effort identification because the motion speed was too fast to identify Direct or Indirect Effort. At the end of the visualization sequence, the “slowly moving outwards from centre to all directions” motion with straight and curve motion path curvature might convey a sense of Direct and Indirect Effort and Sustained Effort. These assumptions are supported by (1) the percentage of correctly identified Indirect Space and Sudden Time Effort (i.e., 33.3% and 75%) and (2) participant feedback on multiple Effort parameter values presented in the visualization (see Chapter 6, section 6.4). For Weight Effort, yellow, yellow-green, and light-green are considered cold or warm colours and can be perceived as Strong or Light depending on colour intensity. This subjectivity of colour perception could also be a factor leading to incorrect Effort parameter values identification. Additionally, the increasing colour intensity was not clearly represented in Light Effort. These problems were reflected by a fair percentage of correctly identified Light Weight (i.e., 58.3%) and that approximately 25% of participants could not identify Weight Effort, whether it was Light or Strong. Taken altogether, the problems resulted in no correctly identified Flick Effort (i.e., 0%; see Appendix C, section 2.3.1 and 2.3.7).

For system B, the “bursting out or moving outwards from centre to all directions” motion direction with straight motion path curvature can convey a sense of Direct Effort instead of Indirect Effort. For Weight Effort, system B used a similar colour scheme to system A.
but some colours in the Flick colour palette have high colour intensity and value (i.e.,
yellow-orange) that can cause a sense of Strong Effort instead of Light Effort. This might
have conflicted with the decreasing shape size and fading out motion that was intended
to convey a sense of Light Effort. These problems were reflected by a low and borderline
percentage of correctly identified Space and Weight Effort (i.e., Indirect [41.7%], Light
[50%]). In addition, about 33.3% of participants could not identify whether Space and
Weight Effort were Direct or Indirect and Strong or Light according to task 2 of the
questionnaire (see Appendix C, section 2.3.8). Sudden Time Effort, on the other hand,
was well communicated (i.e., 83.3%) because of the accelerated motion in the beginning
until the end of the visualization sequence. Taken altogether, these problems resulted in
a borderline percentage of correctly identified Flick visualization (i.e., 50%; see Appendix
C, section 2.3.2 and 2.3.8).

Similarly to other Basic-Effort-Actions visualization, System C’s primary issues were
Space and Weight Effort communication because of the overall abstractness and
quickness of visualization. This is because the stochastic L-system by nature generates
less predictable output visualization. The colour palette comprises various colours, which
made it difficult for participants to use colour as a reference for identifying Weight Effort.
These problems resulted in a low average percentage of correctly identified Indirect
Space and Light Weight Effort (i.e., Indirect [41.7%], Light [25%]). However, Sudden
Weight Effort was well communicated because of the hectic animation speed (i.e.,
83.3%).

These results suggest that system B is the best design strategy for representing Flick
visualization because it performed better than systems A and C in term of the
percentage of correctly identified Flick visualization. However, we cannot conclude that
system B’s design strategy is the best because there is a significant difference in
correctly identified Flick visualization, which indicates that system B performed better
than system A. This means systems B and C equally communicated Flick visualization,
as did systems A and C. Additionally, there was no difference in correct identification of
three Effort parameter values for Flick visualization, and all EMVIZ systems equally
communicated Space, Weight, and Time Effort (see Chapter 6, Table 6.10).