MEANING FROM MOTION: EXPLORING THE AFFECTIVE PROPERTIES OF SIMPLE ANIMATION

by

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Abstract

Recent work has shown the potential of basic perceptual properties of motion for notification, association and visual search. Yet evidence from fields as diverse as perceptual science, social psychology, and the performing arts suggests that motion has a much richer communication potential in its interpretative scope. A long history of research in the affective properties of motion has resulted in a bewildering plethora of potentially rich communicative attributes. However, we have little empirical evidence on how and whether these perceptual effects can be computationally manipulated in a display environment as variables of affective communication.

In this research we explore how attributes of simple motion contribute to emotional interpretation. Our results show that even small abstract motions can reliably evoke affective interpretations given particular motion attributes. In particular, speed and trajectory strongly influence motion interpretation. These results have implications for the design of affective user interfaces and information visualizations.

Keywords: Animation; Affective User Interfaces; Information Visualization; Perception

Dedicated to my husband Ankur, with love

"Do not seek to follow in the footsteps of the wise. Seek what they sought."

Matsuo Basho

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Chapter 1

Introduction

Evidence from studies in psychology and information visualization shows that motion is a powerful conduit of visual information. Recent work has shown the potential of basic perceptual properties of motion for notification, association, and visual search [6, 7]. However, evidence from fields as diverse as perceptual science, social psychology, and performing arts suggests that motion has a much richer communication potential in its interpretative scope.

This research is primarily concerned with exploring semantic attributes of motion in communicating information. Though motion is the most powerful visual cue, yet it is least understood in digital communication. It has a lot of potential and can be applied to visualization or techniques for ambient displays, alerts, cognitive signals, and awareness tools. We are particularly interested in exploring expressive movements including emotional movements, and as we accomplish this, we will investigate and establish the key properties and factors in meaningful motion. Our research has a goal of determining whether and how perceptual affects and impressions can be computationally manipulated in a display environment as variables of affective communications.

1.1 Simple affective motion

The communication of emotion and the creation of affect are core to creating immersive and engaging experiences in performance, interactive art and gaming. They also play a significant role in ambient cues that determine how any given environment "feels." Our research explores the design space of affective motion cues: simple, small motions that can contribute to affect. Although there are multiple definitions of affect, the most relevant to our work is that of experience: when we are affected by something, we experience an emotion as a result. Because motion is still a relatively underused modality, and because motion is very perceptually and interpretatively rich, we are interested in how we might use simple motion to represent emotion and create affect in user interfaces.

1.2 Application and use of affective motion

Much of the work in exploring the subtle characteristics of motion and its contribution to affect has concentrated on animation: appropriately produced movement for objects and articulated figures. We differentiate motion from movement. Movement comprises of two semantic elements: what the moving object implies or affords (a waving hand is aesthetically and communicatively different than a waving flag, for example), and what the motion of the object suggests (e.g. waving as opposed to pointing or stabbing, bouncing as opposed to jittering). Isolating the motion from the object begs the question of how communicative the motion alone may be. Various studies show that humans are capable of perceiving and even identifying emotions from sparse, abstracted animations of point-light displays [17, 38]. A rich history of performance, animation and the construction of engaging experiences suggests that motion can be highly evocative in both traditional user interfaces and more distributed, ambient applications.

We can apply motion directly to a particular object (such as an icon) to convey properties associated with that object: a common example might be an alert signaling that your favorite country just increased its medal count during the Olympic Games (happy) or an angry message from a friend [44]. Ambient applications are more experiential, in that motion may be applied as a sort of environmental "texture" or brush to create an aesthetic effect or evoke an impression. Consider the ubiquitous screen saver or background displays. Because we are interested in how motion might be added to user interface elements and environments as an additional expressive modality, we are interested in the affective scope of relatively small motions. It is readily apparent that motion is a rich conduit of information flow from our surrounding environment. What remains to be established is the means by which these perceptual effects and impressions might be usefully manipulated in a user interface to communicate meaning or create an atmosphere (to set the scene, as it were).

1.3 What's in a motion? The research question

While there are a number of parameters by which a motion can be described, little is known about which dimensions are most responsible for conveying meaningful information through motion. Previous studies have suggested the following as candidates: velocity [1, 3, 38], amplitude [1, 47], acceleration [38], direction [3, 45], shape [6], effort [24], and trajectory [3, 45, 47], including smoothness and jerkiness. While these studies point out how particular attributes of motion contribute to convey certain meaning, each considered only a subset of the attributes above. Further, this set does not represent a clean space of orthogonal dimensions, but rather a list of influential factors that "overlap" each other (e.g. direction, shape and trajectory are neither exclusive nor isomorphic).

For computational tractability we need to reduce this parameter space to a set of dimensions that can be algorithmically identified and manipulated. In this thesis, we describe an empirical investigation of how attributes of simple motion contribute to emotional interpretation. Our results show that even small abstract motions can reliably evoke affective interpretations given particular motion attributes. In particular, speed, trajectory, and position strongly influence motion interpretation. These results have implications for the design of affective user interfaces.

1.4 Thesis overview

This thesis is organized as follows. Relevant research in perceptual and social psychology as well as information visualization is reviewed in Chapter 2. The chapter provides a review of the use of affective motion as communication. Our research goals, motivation, and approach are described in Chapter 3. We also describe the method of capturing expressive human arm movements using motion capture (mocap) system.

Two sets of experimental studies were conducted for this research. The first study, described in Chapter 4, determined what the dominant dimensions are in distinguishing different types of motions. In this study, three experiments were conducted using a small, simple motion. The first experiment, designed as a pilot study, examined both algorithmically and non-algorithmically generated motions. The other two experiments used only the mocap motions - motions captured using mocap system. Chapter 5 describes the methodology and reports the results of another experiment that shows how particular attributes of simple motion contribute to certain emotional interpretation.

Finally, Chapter 6 concludes the thesis by providing a summary of the results and the design implications for information visualization and user interface.

Chapter 2

Background

Motion is a powerful visual cue and has been found to be useful for tasks such as notification [7], visual search and emphasis [6], and tracking transitions [40]. Motion has also been shown to convey meaning, emotions [27], and intentions [16]. Two of the most interesting applications to user interface experience have been kinetic typography [26, 50] and gestural capture for emotional expression in social tools [20, 44].

Character animation relies on the exaggeration of movement to deepen our understanding of behavior and motivation [46]. The arts of drama, dance and music map very complex emotions and motivations onto gestures and movement. While there are vocabularies of movement that formalize expression, notably acting [52], choreography [24] and well-known techniques for character animation [46], computer scientists have no rigourously validated understanding of the semantics of motion, nor of how these might be used to convey meaning in the abstract representations used in information visualization and user interfaces in general. Dancers, actors and performers, on the other hand, have a deeply ingrained knowledge of movement and meaning, but less understanding of how this might be translated into computational rendering that reliably elicits the desired effect.

Researchers have studied a variety of emotions elicited by animations of both veridical figures (depiction of a body) and more abstract point-light displays that convey an articulated figure [38]. However, the study of representation, perception and understanding of meaningful and expressive motion on display, is still in its preliminary state in information visualization research. In this chapter we explore previous work from various domains including perceptual and social psychology.

2.1 Affective movements

We first explore related work in the study of expressive human movements. Many studies investigate how to generate meaningful animation on displays by conducting careful analysis on the movements and postures from captured expressive human movements.

2.1.1 Gestural expressions

Body movement is highly expressive of emotion and highly affective [3, 47]. Humans perceive and express affect in various ways using different body parts and patterns; we use facial, gestural, postural, or vocal expressions. Particularly, there has been extensive work done on the analysis and generation of facial expressions and movements. Cunningham et al. examined the possibility of generating realistic, recognizable facial expressions in computer-generated animation by conducting studies on human perception of captured facial expressions and rigid head motion [14, 15]. The recognition of the 3D facial animation generated based on their analysis was comparable to that of the real faces [49].

On the other hand, some studies are devoted to arm and hand expression only, although the level of the analysis is not as high as the facial expression. Hand gestures, often together with speech, reveal mental images as physical forms, and even have an impact on thought [33]. They can efficiently convey ideas that even language fails to express. Wallbott discovered that different emotions are significantly associated with different hand and arm postures and movements, in comparison to the movements of other body parts [48]. Music conductors, in particular, convey expression and communicate artistic directions through hand and arm gestures only.

Using a set of animations of embodied agents, Marsella et al. explored Delsarte's description of hand gestures and attitudes of the hand for different expressions [32]. The technique systematically described both movements and orientations of body parts in space. In this study, hands of a virtual character interacted with an imaginary cube to show expressions such as rejection, possession, and support. For example, putting palms of the hands on the bottom surface of the cube was supposed to express support. The authors discovered that the animations indeed provided consistent interpretation and confirmed Delsarte's description empirically.

2.2 Perception of schematic representation of biological motion

Johansson defines patterns of movement in living organisms as biological motion [23]. Particularly, biological motion produced by point-light display of a moving human body represents very well the details of what the body is engaged in. Various studies have reported that we can correctly identify different kinds of affects from point-light display or silhouette of biological motion [9, 12, 13, 18, 17, 38, 39]. The studies are significant because facial expressions are completely removed from the images and only joint movements are visible.

The results of Dittrich et al. for full-body dance movements with six different emotions (fear, anger, grief, joy, surprise, and disgust) showed high recognition rates for point-light displays [17]. Similar results were obtained for knocking and drinking arm movements with ten different emotions (afraid, angry, excited, happy, neutral, relaxed, sad, strong, tired, and weak) [38]. These results encourage our speculation that motion itself, or arm movements in particular, may carry rich expressive information.

One may argue that a point-light display contains much more information than just motion, such as the shape that a collection of points may form. However, Pollick et al. [38] showed that even when the point-light image of arm movement was phase-scrambled and upside-down, which completely removes the impression of arm, participants still recognized emotions well. Similar results were obtained by Dittrich, et al. with an upside-down point-light display of dance movements [17]. Emotions were also well identified from silhouette of dancers in dark suits performing to express anger, fear, grief and joy [9].

2.3 Abstract movements

While many studies rely on the depiction (however abstract) of an articulated figure, several researchers have investigated the affect of more abstract motion. Although biological motions can better convey affect, humans can also perceive meaning from abstract movements. In several studies, participants attributed very complex motivations and emotions to a set of animated geometric primitives [4, 16, 21, 27] or even to a single animated dot [45]. Some of these studies were well reviewed in Scholl and Tremoulet's article on perceptual causality and animacy [42], which discussed that potentially simple animation could surprisingly result in impressions indicating high-level cognition. The article also demonstrated the classic work of Heider and Simmel, which investigated the perception of a moving picture-film with a large triangle, a small triangle, a circle, and a rectangle with a 'door,' which opens and closes [21]. In their study, observers attributed very complex motivations and emotions to a set of these animated geometric primitives, anthropomorphized the objects and described them as 'animated beings.'

On the other hand, Barrett et al. explored intentional interactions such as chasing, fighting, and guarding that are crucial to survival and reproduction across all animals [4]. In their experiment, observers were able to identify the intentions by seeing two cursors on a blank screen moved by two participants with a particular intention in mind. This study is particularly interesting, since the cursors were moved by human hands, yet the representation was completely abstract.

Lethbridge and Ware created stimulus-response animations in which objects in a geometric shape respond to stimuli in the environment such as velocity of its own or others in order to create a new environment [27]. Observers attributed emotions such as aggressiveness and anxiety based on the moving objects. In a similar manner, Dittrich and Lea [16] investigated intentional motions by algorithmically manipulating different motion parameters on a set of moving letters. In the study, one of the moving letters was designed as a target or 'wolf,' and all of the others were designed as distractors or 'sheep'. The target letter tried to track or 'stalk' one of the distractors on a display, and observers were asked to identify the target letter and rate its degree of purposefulness, interaction, and animateness. The study demonstrated that such simple stimuli could provide the perception of intentionality depending on the variation of motion parameters. Manipulating different motion parameters, such as directness of the target's movement or relative speed between the target and the distractors, improved the recognition of intentions, and the purposefulness and animateness were perceived better.

2.4 Basic emotion

Different movements give different impressions and therefore communicate different experiences. At the same time, the same motion can also provide different experiences depending on the viewer. Moreover, the definition or experience of emotion itself can vary between different people. Fortunately, there are some emotions whose experiences are relatively consistent among all people. Psychologists often define these emotions as basic or fundamental emotions to separate them from other more complex emotions.

When determining whether the emotion is basic, many emotional theorists are usually concerned with its universality across cultures or humans and even other animals. The basic emotions also have to be distinguishable with each other to avoid misinterpretation. Ekman proposed the following emotions to share these characteristics: amusement, anger, contempt, contentment, disgust, embarrassment, excitement, fear, guilt, pride in achievement, relief, sadness/distress, satisfaction, sensory pleasure, and shame [19]. Although not all emotion theorists agree with Ekman's definitions, there are some emotions that almost every emotion theorist agrees to be fundamental: anger, happiness, sadness, and fear [22, 37]. Body movements have been shown to communicate these emotions effectively because gestures and postures reflect the emotions in a familiar and recognizable manner [9, 3].

Other basic emotions proposed by one or more emotion theorists include aversion, courage, dejection, desire, despair, hate, hope, love, interest, surprise, wonder, sorrow, rage, terror, anxiety, elation, subjection, tender-emotion, pain, expectancy, panic, acceptance, and anticipation [37]. Most of the previous studies on emotional movements presented in this chapter investigate a subset of these basic emotions.

2.5 Emotion dimensions

Emotions have traditionally been ranked on a *valence* dimension, which is also known as *pleasantness* dimension (positive/negative). Recent research considers two additional dimensions of emotion: *arousal* and *dominance-vulnerability* [43]. These provide more nuanced ways to empirically distinguish emotions. Arousal (also known as *activation*) concerns the intensity of the emotion. Dominance-vulnerability, related to aggression, provides a way to distinguish empirically between emotions that are similar in the other two dimensions, such as fear and anger, and sadness and contempt.

Wallbot analyzed body movements and postures and concluded that there are associations between movements and emotions due to the dimension of arousal [48]. For example, lateralized hand/arm movements, arms stretched out to the front, and opening and closing of the hands, were observed during "active" emotions, such as hot anger, cold anger, and interest. In recent research, emotions are encoded on a display as a combination of valence and arousal to show more distinguishable emotions and to enhance the user's emotional experience [20, 50]. Wang et al. mapped user's arousal to the speed of animated chat text, based on real-time electrical resistance of the user's skin!

2.6 The elements of affective motion

According to previous studies referenced earlier in this chapter, it has been established that motion is a rich modality for communicating emotion and creating affect. Now the question is, what makes motion meaningful? A number of researchers have attempted to categorize movements derived from performing arts, notably the Laban taxonomy for choreography [24], into parameters discernible and distinguishable by humans [47].

Laban and Lawrence [24] described human movements based on effort using four sub-categories, each of which is an axis in the 4D space:

- Space (indirect - direct) describes mover's approach to the environment
- Weight (strong - light) describes mover's attitude toward the impact of his/her movement
- Time (sudden - sustained) describes mover's exertion in time
- Flow (bound - free) describes mover's attitude towards the continuity of his/her movement.

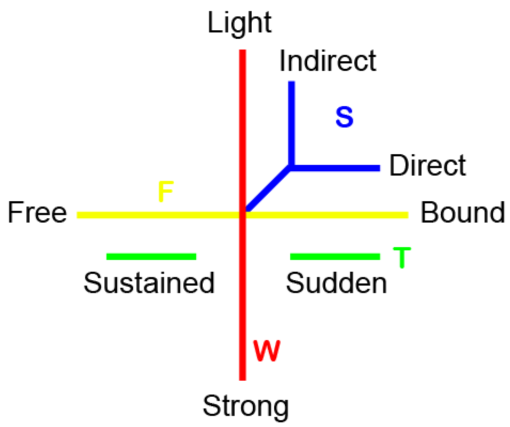


Figure 2.1: Efforst space

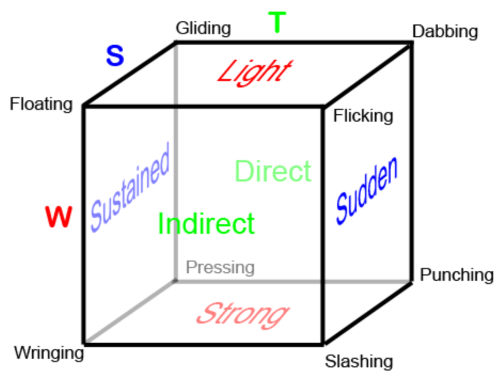


Figure 2.2: Exertions

Figure 2.1 shows the described 4D space. The letter W is used to represent weight, S is for space, T is for time, and F is for flow. Basic actions usually deal with W, S, and

T, and not necessarily include F as a factor. The combinations of three motion factors W, S, and T yield the following eight basic exertions: "slashing, gliding, pressing, flicking, wringing, dabbing, punching, and floating." In Fig 2.2, each corner represents one basic effort, and any two efforts connected by a line share two elements in common. For example, floating and flicking share W and S, but they have an opposite T. The authors stress that there is an appropriate combination of these factors to define a task and a inappropriate combination results in a failure of the task. For example, a task "swinging of a heavy object" can be appropriately done by a combination of "sudden, indirect, free, and strong," while "depositing a light object" can be accomplished by "sustained, direct, bound, and light" movement. Although Laban's work was originally directed towards performing arts, it has also been applied to different fields. Chi et al. [11] created a 3D character animation system called EMOTE (Expressive MOTion Engine) which incorporated Laban's Effort and Shape ("changing forms that the body makes in space") components to create more believable animated characters with natural, expressive arm and torso movements.

In a more recent study, Vaughan [47], from the point of view of performing arts, summarized the minimum characteristics of movement on the screen for humans to perceive meanings of movements as follows:

- Speed: speed or tempo of the moving object
- Area/Space: the space used by the moving object
- Direction: direction of the movement
- Path: the line the moving object creates

These reflect the well-know techniques used by animators, who rely on speed, extent and amplitude to convey emotional state of their characters [46]. Music conductors convey expression and communicate artistic directions through movements. Although there are no universal rules or patterns for conducting, there appear to be certain dimensions to communicate musical expressions to the performers. These expressive dimensions include movement amplitude, shape, and temporal continuity [41].

We now take a close look at each individual parameter.

2.6.1 Speed/Tempo/Acceleration

Speed[1] is listed as one of the fundamental principles of traditional animation, as it is often associated with the weight or size of the objects or the force exerted on the objects [3, 25]. Big objects tend to move slower because they require more force to move them than smaller ones. Quick movements are often associated with a greater force on the object than slower ones. Not only does speed convey the physical characteristics of objects or the events happening to them, it may also convey emotional meaning [20, 25, 50]. Pollick et al. indicated that energetic motions such as angry, excited, strong, and happy arm movements, were significantly associated with bigger speed [38]. They also discovered that these energetic motions were significantly associated with greater acceleration and deceleration.

2.6.2 Space/Amplitude

Space or amplitude is another candidate attribute [1, 9, 47, 48]. Some motions or states such as anger, joy, despair, and power are often seen with large, expansive movements, while other emotions or states such as fear, grief, sadness, disgust, weakness, or boredom, are often associated with motions with smaller amplitude or body contraction in dance movements. The former includes more energetic states than the latter.

2.6.3 Direction

Direction is also a well-studied property of motion which is believed to be one of the expressive qualities of movements [3]. The authors in [4] suggest that direction, as well as velocity and the distance between two interacting objects, may be useful for distinguishing intentions. Changes in direction move viewers' attention, and the direction itself has certain meaning; object moving upward have "positive associations or an increase in magnitude", and vice versa; objects moving towards right have "forward momentum" while movement to the left implies "a reversal of time or feeling of losing ground" [2, 3]. Mutlu et al. installed a dynamic social interface consisting of twelve circular shapes that move in certain directional patterns to convey certain emotions; attraction towards the center conveys happiness, while randomness and self-directedness conveys curiosity [34]. The installation proved to

[1] in this thesis, we use the term speed rather than velocity to describe a distance an object moves in unit time, as velocity is a vector quantity which describes both speed and direction of the moving object

(a) straight (b) arch (c) angular (d) meandering (e) self-intersection

Figure 2.3: Tagiuri's trajectory paths

contribute to a better social interaction due to people's perception of the emotional content in the interface.

2.6.4 Trajectory/Path

Trajectories of moving objects form shapes, and different shapes can be formed by presence or absence of directional changes over the time. Tagiuri investigated single dot animations and found different trajectories eliciting particular impressions [45]. Sample paths are provided in Figure 2.3. Straight paths (Figure 2.3a) were perceived as "determined, alert, aggressive, and purposeful" while arch-like paths (Figure 2.3b) were perceived as "unhurried, unsure, happy, and relaxed." Meandering paths (Figure 2.3d) were perceived as "immature, confused, upset, and curious," and such highly erratic paths also led to the impression of a drunk and disorderly dot!

The author suggested that angle of movement and distribution of the path's angle, with respect to the *goal*, might be the key factors in conveying emotional content. Is the movement *toward* or *away* from the goal? According to the author, the former implies *approach* and the latter implies *avoidance*. Therefore, he concluded that paths with a mix of approach and avoidance angles could suggest "approach with caution" or "hesitation," while a path that consisted of only approach angles potentially implied "direct" or "purposeful." Also, a path with a loop or self-intersections (Figure 2.3e), according to him, was an example of the intense change between approach and avoidance.

2.7 Digital modeling of affective motion

Other studies attempt to tie together movement parameterization and emotional perception of gesture and collectively analyze the computational models generated as a result of expressive gestures. The EyesWeb Expressive Gesture Processing Library supports the analysis of human movements with respect to velocity, acceleration, shape, orientation and contraction of the body, and fluidity of trajectories, from real-time expressive human movements and gestures [10, 31]. The system extracts expressive cues from these parameters such as sadness or pleasure. The authors stated that we could use these extracted measurements to group similar gestures that convey the same meaning, but provided no empirical validation.

Amaya et al. [1], on the other hand, attempted to focus on differences in speed and spatial amplitude and created a technique called emotional transform to derive emotional human movements from neutral movements. Their study showed high similarities between recorded real emotional movements and “new” emotional movements rendered by applying the transforms. Omlor and Giese demonstrated that it is possible to reduce the dimensionality of joint-angle motion trajectories by using regression techniques to identify spatio-temporal primitives that are important for visual perception of emotional gaits [36].

Finally, more recent studies incorporate gestural capture to create affect in much smaller media; an emotional text messaging service called eMoto generates affective background for mobile phones [20]. eMoto uses different types of display dimensions such as color, size, and shape as well as motion to communicate different emotions through user’s gestures. For example, intense shaking of the device would create a red background with many fast-moving large bubbles, which communicates high-intensity expressions such as “excited.” On the other hand, swinging would create a blue background with slow-moving large linked shapes, which communicates low-intensity expressions such as “tired” or “bored.”

2.8 Summary

This chapter describes significant research in representation and perception of meaningful motion. The studies suggest that humans are good at perceiving meaningful contents based on visual cues alone. There are suggested key properties and factors in meaningful motion, and some studies succeed in representing certain expressions by effectively manipulating these properties. However, they are not necessarily the most dominant motion attributes in conveying meaning. A motion parameter space is not yet well defined, and therefore the question of which attributes of motion are most effective in coding information still remains unanswered. The next chapter discusses the goal and motivation of our research.

Chapter 3

Goals and Approach

While animation is often used as one of the cues to represent emotion in affective user interfaces [3, 44], there is little research on what aspects of the motion actually contribute most effectively to a desired impression. Previous studies done by other researchers in the fields of motion in performing arts, psychology, and digital communication, as described in Chapter 2, have suggested that motion can be highly useful in both focused (i.e. moticons) and diffuse (i.e. background effects) applications.

Overall, our research is concerned with exploring semantic attributes of simple, abstract motion in communicating information. By conducting an empirical study, we sought to develop a semantic space of motion that can be computationally realized and visualized, to enable meaningful motion-based interaction in the context of visualization, interactive art, or ubiquitous interfaces. Our motivating goal was to lay the guidelines for the use of meaningful motion in digital communication.

3.1 Research goals and approach

The motivation of our research was twofold. The first goal was to explore the creative properties of movement and expression for a deeper understanding of the communicative properties of motion that could be computationally described and modeled. The second was to investigate if and how these properties could be reliably useful. Can we encode them in an abstract manner to convey complex meanings such as emotion, importance, urgency, etc.?

We achieved our research goals by conducting two studies: *similarity* and *interpretation.*

In this section, we discuss more detailed research questions and how we approached them.

3.1.1 Determine the key factors that group similar motions

The similarity study involved an initial empirical classification of simple, small, abstract motions. First, we sought to ascertain what motion attributes, or combinations thereof, may differentiate motions. Our goal was to reduce the dimensionality of the parameter space. This is based on the reasoning that the properties which determine whether one motion is like another likely represent important criteria for characterizing that motion [5]. The approach was based on the speculation that the interpretation of some basic motion is not simply due to individual tendencies but is reliably consistent across people, regardless of their cultural background or individual temperament. Second, we were interested in how these parameters relate to the three dimensions of emotional classification. The investigation of judging similarity between motions might suggest useful dimensions for affective coding.

3.1.2 Determine what makes motion meaningful

We believe that there are appropriate attributes of motion to convey certain meaning, impressions, or intentions. Ideally, we should be able to computationally manipulate them to express certain meanings in a display environment. The ultimate goal of the interpretation study was to determine whether and how particular perceptual effects and impressions could be elicited from small, abstract motion. Our motivation was to understand and characterize the dominant attributes that might enable us to encode meaning into motion (i.e. a visual grammar for motion).

As stated earlier, we focused on what each motion actually communicates and why, rather than what the motion was intended to communicate and how well it was perceived. We analyzed how people evaluate each distinctive motion (selected carefully based on the results of the similarity study) in terms of different expressions. We hope the results of this study will be applied to the development of interactive tools and techniques that provide a language of affective and expressive motion patterns for interaction and user experience designers.

3.2 Overview of the experiments

Chapter 4 covers the similarity study, and the Chapter 5 covers the interpretation study. A total of four experiments done through both studies are organized as follows:

- Similarity
  - **Pilot**: a pilot to the initial similarity study
  - **Experiment 1A**
  - **Experiment 1B**: a control experiment for Experiment 1A
- Interpretation
  - **Experiment 2**

3.3 Motion data

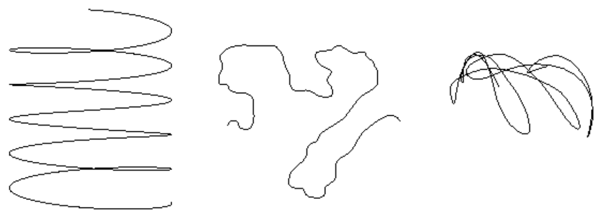
One of the related goals in our study was to understand critical properties divorced from semantics of a moving object. Can we abstract the visual properties that distinguish emotional motions? Are these performer/source dependent? We approached these questions by exploring different types of motions including expressive motions captured from different performers and comparing them with mechanical motions.

We collected and generated a total of 137 motion trajectories throughout the study. They were derived from three sources of trajectory paths: algorithmically generated, hand-drawn, and motion captured, which are described in more detail below. Sample trajectories are shown in Figure 3.1. In Appendix A, we provide trajectory paths for all of the motions that are used in our studies. The demonstrations of all motions used in the experiments are also provided in the attached DVD as described in Appendix F.

3.3.1 Algorithmically generated motions

Seven motions (Motion ID 1 through 7 of Table A.1 in Appendix A) were generated using simple mathematical equations, and eight motions were generated from Ware's random motion generator [51] (Motion ID 8 though 15).

We used periodic, algorithmically generated motions for two reasons: 1) they are common and 2) they have no inherent meaning in their generation.



(a) Algorithmically generated (b) Hand-drawn (c) Motion captured

Figure 3.1: Sample motion trajectory paths

3.3.2 Motions from hand-drawn trajectories

We have implemented the path trajectories of five of the motions identified by Tagiuri (Motion ID 16 through 20) as provoking the most complex responses (such as "irresponsible" and "purposeful"). We chose these because his work concentrated so closely on pure motion as opposed to moving objects. A meandering trajectory such as the one shown in Figure 3.1b could be perceived as immature, drunk, and stupid; on the other hand, a straight path was perceived as determined, aggressive, and purposeful, while an arch path was perceived as relaxed, happy, and unsure. Tagiuri's work is reviewed in detail in Chapter 2.

3.3.3 Motion capture of expressive human movements

In this research we were interested in evaluating small, abstract movements that were derived from real human arm movements. As discussed in Chapter 2, arm movements carry rich expressive information which is substantially more than the information from motions of other body parts. The Vicon mocap system was used to capture arm movements of our performers. The elaborate arm movements were captured as simpler, small motions in our analysis.

Two sensors were attached to the performer's arm to capture movements; one sensor was attached to the performer's elbow and the other sensor was attached to the wrist. Each motion was then mapped to a simple dot, normalized into a common frame size and time (5 seconds). That is, we anchored the captured positions of the sensor attached to the elbow to show the relative positions of sensor attached to the wrist in a display. In the experiment, a small dot followed the trajectories so that the user could perceive the motion. We used only one dot rather than two dots for two reasons: 1) we wanted to generate simplest possible animation and 2) avoid the impression that the two dots are trying to interact with each other. All movements were captured at 60 frames per second.

Performers

We captured arm movements of three different performers using the mocap system to create simple motion in a display. One performer (Performer 1) was a music conductor, another performer (Performer 2) was a regular, unspecialized expressive person with no formal movement training, and the last performer (Performer 3) was a trained dancer/actor.

Prior to obtaining the motions from the performers mentioned above, another trained dancer volunteered to provide motion captured movements for a pilot study. These motions were only used in the pilot study, hence we refer to this performer as Performer A to separate from others.

We realize that the formation of emotional gestures may be highly specific to culture and profession, but as our concern for this study was to examine what properties of motions affect how viewers interpreted motion types, and not how accurately they matched what the performer intended, we were less concerned with the cultural differences between performers.

Expressions to be coded in movements

We instructed the performers to move freely with one of the following 32 expressions in mind: contentment, discontent, pleasure, pain, pride, shame, joy, sadness, anger, calmness, excitement, indifference, fear, fearlessness, innocence, guilt, amusement, annoyance, interest, boredom, worry, relief, admiration, contempt, attraction, disgust, importance, unimportance, relaxing, urgency, welcoming and rejecting. These expressions included basic emotions suggested by one or more of the emotional theorists introduced in Chapter 2 as well as more abstract qualities that we were interested in examining, such as urgency, importance, and interest.

We also gave Performer A the same instruction, but we provided her with only 10 expressions: joy, disgust, importance, fear, anger, aggression, resisting, welcoming, sadness, and boredom.

3.4 Motion properties for investigation

Determining the emotional elements of motion requires good samples of movements that can be easily characterized by a small number of parameters and at the same time efficiently understood by humans. We first determined a set of independent properties which authoritatively defined the motion space by collecting evidence from previous work.

Previous studies reviewed in Chapter 2 have suggested candidates for motion attributes to convey meaning. However, these studies considered only a subset of the attributes or specific aspects of motion. In contrast, we were concerned with exploring the relative, cumulative contribution of all of the attributes - in other words, determining how they fit into an overall design space for motion coding. Therefore, we conducted a collective study of motion properties to ascertain validity of previous assumptions based on individualistic motion property analysis.

We considered the following motion properties in our study.

- Speed
- Amplitude
- Acceleration/Deceleration
- Frequency
- Direction
- Shape
- Fluidity
- Path self-intersections
- Directional changes
- Positions
- Emotional contents

The trajectory attributes were derived from [45]. The definitions for some of the parameters above were changed or improved throughout the studies. Table D.1 in Appendix D shows the definitions used for each experiment.

Chapter 4

Similarity

The similarity study reported here was designed to provide an initial empirical classification of small, abstract motions. To start with, we speculated that the combination of characteristics that determines whether one motion is like another potentially represents important criteria for characterizing that motion.

Three experiments investigated which motion attributes are dominant in identifying similar motions. All of the experiments reported here involved people making a single judgment of similarity between two motions. We did this by first collecting a large set of distinct motions and then comparing every possible pair of motions. We sought to ascertain what motion attributes, or combinations thereof, might differentiate these motions. Our goal was to reduce the dimensionality of the parameter space.

The three experiments reported in this chapter are: (1) Pilot, a trial version of the two experiments that followed (2) Experiment 1A, which investigated a larger set of expressive motions, and (3) Experiment 1B, a control study, designed to verify the results obtained in Experiment 1A.

4.1 Pilot

4.1.1 Goal of study

The main goal of the pilot study was to consider a superset of possible attributes that participants might find helpful in characterizing the motion. After the analysis of results obtained from the pilot study, attributes that were not found significant would be discarded or revised when conducting the subsequent experiments. Another important goal was to examine whether the emotional contents of mocap motions encoded by performers could be distinguished from algorithmically generated motions.

4.1.2 Task and method

Participants sat in front of a standard 20" computer monitor of 1280x1024 resolution and were presented with the experiment screen (Figure 4.1). Motions were rendered with a small unicolour sphere (we used 3D to replicate the paths of any motions captured from human gesture as well as Ware's random motions and spiral motions). Participants were asked to rate similarity between the motion on the left side of the screen (the *source* motion) and each of nine motions in the grid on the right side of the screen (the *target* motions) on a 5-point semantic differential scale where 0 meant "dissimilar" and 5 meant "very similar." The default rating was set to 0.

Each screen constituted one trial and involved 9 comparisons. When a trial started, none of the motions were active. The participant selected "Start" (underneath the source motion) to activate the source motion. Then (s)he activated a target motion by holding the mouse over its area in the grid. Moving the mouse pointer away stopped the motion. Thus only two motions were ever concurrently active: the source and the particular target of interest. Participants were asked to look at each motion before any of them could be rated. There was no timing constraint on the trial, during which the participants could play a motion as often as they wished and could adjust their ratings as desired, before pressing the "Finish" button to go to the next trial. Each of these motions was represented on the screen as an image of size 150x150 pixels to give equal weight to every motion. All displays were constructed using JOGL (3D Java).

4.1.3 Motions

For this initial study, we chose thirty motions with different trajectories, generated both algorithmically and non-algorithmically. Thirty motions included all of the motions in Table A.1 (motions derived from simple mathematical equations, Ware's random motion generator [51], and the hand drawn trajectories described in [45]) and Table A.2 (the arm movements of Performer A, captured by mocap system). These motions were discussed in detail in Chapter 3. As mentioned earlier, our intention in mixing three sources of motions

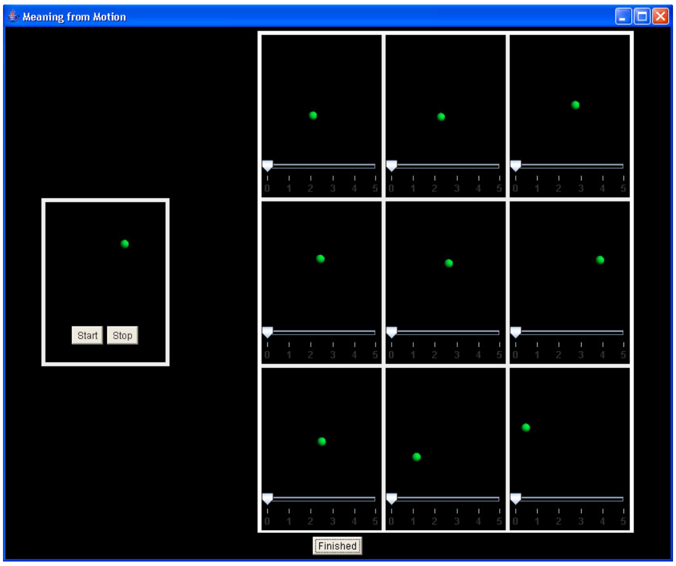


Figure 4.1: Pilot experiment screen capture

together was to see whether the inclusion of emotional contents by the performer could affect people's perception about the motions.

4.1.4 Motion attributes

The following is a list of attributes we investigated in this experiment. The basis of choosing these attributes was to take into consideration the findings of previous studies (regarding important motion attributes) and also do an analysis of the collective impact of all the attributes identified in these independent research studies till now. (For further discussion, please refer section 3.4.)

- Speed (Speed)
- Amplitude (Amplitude): maximum distance between two points in the trajectory
- Acceleration (Acceleration): number of times acceleration occurred
- Deceleration (Deceleration): number of times deceleration occurred
- Frequency (Frequency): number of times motion repeats itself in one time frame
- Direction (Direction): diagonal, major axis (X or Y), or random

- Curviness (Curviness): curvy, straight, or combined
- Shape (Shape): circular, linear, arch, spiral, random, or a combined
- Path self-intersection (SelfIntersection): number of self-intersections
- Open/closed path (Open/Closed): open or closed
- Sharp directional changes (SharpChange): number of directional changes where the angle of two path segments is smaller than 90 degrees
- Obtuse directional changes (ObtuseChange): number of directional changes where the angle of two path segments is smaller than 135 degrees but greater than or equal to 90 degrees
- Emotional contents (Emotion): emotional or algorithmic

We were interested in finding whether the ratings we obtained have any correlation with the motion attributes. Therefore prior to having the participants compare the motion, we analytically characterized each possible motion combination. Each pair was uniquely described by a difference vector that calculated the absolute distance between each of the motions' dimensions (the factors). When the difference was nominal (as in the Direction and Shape factors), we used a simple distance metric by assigning an ordinal value to each level in the factor and calculating the difference between these ordinal values. So, for example, in the Curviness factor motions were assigned the ordinal values of curvy = 1, combined = 0, and straight = -1, thereby ensuring that a curvy motion was evaluated as being more distinct from a straight motion than it was from a combined motion. This approach of assigning ordinal values was also extended to the Emotion factor of the motion where boolean values were assigned to each comparison. A value of 0 implied that the motions were either both emotional (i.e. generated by a human according to instructions of enacting "emotional" gestures) or both non-emotional (i.e. algorithmic), and 1 implied that one motion was emotional while the other was non-emotional.

4.1.5 Hypotheses

We had three hypotheses:

- Speed and amplitude would be the most influential factors.

- Emotional motion could be distinguished from algorithmically generated motion.
- Trajectory information such as shape and curviness would be important factors.

4.1.6 Participants

Five SFU students participated in the experiment. All had normal or corrected-to-normal acuity and normal color vision, which was stipulated as a precondition when recruiting participants. None had participated in previous experiments in this area. All were naive to the purpose and hypotheses motivating the study.

4.1.7 Block design

There were 435 possible pairs of motions and five participants. In order to limit the number of the screens to be seen by each participant, we randomly generated twenty-four trials for each participant so that the same pairs of motions would be seen at least twice and at most four times throughout all five participants. Twenty-four trials were then divided into two blocks, each consisting of twelve trials, for each participant. These blocks were created only to allow participants an opportunity to take breaks during the experiment. The typical session for one participant lasted about 45 minutes.

4.1.8 Results

Stepwise regression was used to ensure that we obtain the smallest possible set of attributes to provide a useful estimate of similarity rating. Our results were as follows: Adjusted R square = .376; F = 30.005; $p < .0005$. Significant attributes are shown in Table 4.1. Deceleration, Direction, Open/Closed, and Curviness were excluded from the model, hence they were not significant attributes. Table 4.1 shows that Amplitude, Shape, SharpChange, and Acceleration to be the most significant attributes in judging similarity.

What do these statistics tell us in practical terms? First, as we expected, Amplitude had the strongest effect on how similarly two motions were rated: overall the greater the difference in Amplitude, the lower the similarity. Shape and SharpChange also played strong roles. Speed, on the other hand, had a smaller effect than we expected. All of the factors except SelfIntersection had similar, negative correlations, although the effects may not be noticeable for some of the factors. The results also suggested that the participants were able to distinguish between emotional and non-emotional motions, supporting our hypothesis.

The authors are aware that the sample set of data used in the pilot along with the small size of participants is not sufficient to make any statistical claims with a comfortable degree of confidence. Hence, the pilot study has merely been used as a proof of concept and has not led to exclusion of any motion attributes which might be pertinent and significant.

Factors	Estimated Effect	p
Amplitude	-.344	.000
Shape	-.292	.000
SharpChange	-.239	.000
Acceleration	-.147	.000
Frequency	-.116	.003
ObtuseChange	-.102	.008
Emotion	-.093	.019
SelfIntersection	.093	.036
Speed	-.085	.035

Table 4.1: Significant effects (Pilot)

4.1.9 Discussion

Our results showed that particular attributes of motion seemed to have a dominant effect on similarity judgment. It appeared that emotional motion could be distinguished from non-emotional motion, which encouraged us to further investigate mocap motions. One of the participants told us at the end of the experiment that jiggly (jerky) motions were easily distinguished from smooth motions. The fact that SharpChange was significant could explain the reason for this statement; more sharp turns the motion made in a certain time frame, more jerky it looked.

Another important consequence of the pilot study was the deeper analysis of the mocap motion captured using our performer. It was observed that the dance motions from the pilot were not "evocative" enough as they were slow and deliberate. In order to obtain "better" motions with a clearer depiction of the emotional content, we decided to capture more emotions using different performers, thereby increasing our chances of soliciting better feedback from our participants.

This was just an initial step in determining potential candidates for attributes that distinguish one motion from another and their relative contribution. One major motivation behind conducting this pilot study was to determine if our adopted approach was even feasible, and upon analysis, the results were found encouraging enough to warrant more extensive study. Our next step would be to investigate how these results could be used to refine our motion attribute candidates.

4.2 Experiment 1A

Taking the results of the Pilot experiment into consideration, another experiment was conducted on a larger set of mocap motions to explore the three dimensions of emotional classification reviewed in Chapter 2. Before we begin to explore the interpretative scope of motion coding, we needed to more precisely characterize what distinguishes one motion from another. In particular, we were concerned with how emotional motions were differentiated: that is, motions used to express basic emotional experience. A subsequent study will compare effects across different performers and participants.

4.2.1 Goal of study

We had two goals. The first goal was same as the Pilot study: we sought to ascertain what motion attributes, or combinations thereof, might differentiate two motions. Second, we were interested in how these attributes related to the three dimensions of emotional classification.

4.2.2 Task and method

The participant sat in front of a 24" computer monitor of 1920x1200 resolution on which was centered an experiment screen with a set of 32 motions. These were structured with a source motion in the center surrounded radially by 31 target motions as shown in Figure 4.2. Each of the target motions had a rating slider underneath it ranging from -2 to +2 by increments of 1.

Each screen constituted one trial and involved 31 comparisons. When a trial started, none of the motions were active. Activation of a source and target motions was done in the same manner as the Pilot experiment. After viewing a target motion for a minimum of 5 seconds the participant could then rate the motion for its similarity to the source using the slider, where -2 meant "very different" and +2 meant "very similar". There was no timing constraint on the trial, and participants could play a motion as often as they wished and

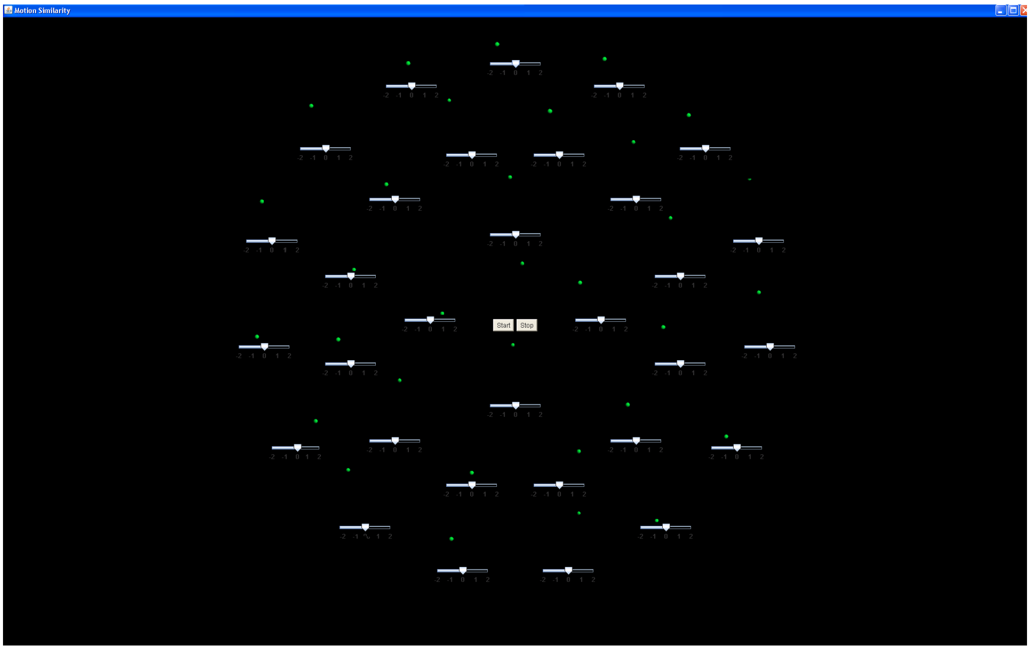


Figure 4.2: Experiment 1A screen capture

could adjust their ratings as desired.

Once a motion had been rated its slider was shaded to indicate the decision. A participant was allowed to proceed to the next trial only after all of the 31 target motions had been rated. The participants were given unlimited practice time to explore all 32 motions in advance to form a scale of their judgment on similarity. Throughout the experiment, they could replay the animation or change the rating at all times for as many times as they wanted, before pressing the "Finish" button to go to the next trial.

Each of these motions was represented on the screen as an image of size 110x110 pixels to give equal weight to every motion. The duration of each motion was five seconds, and the motion repeated itself thereafter in a loop.

4.2.3 Motions

Experiment 1A used a set of captured motions of Performer 1, the conductor. Conductors are experienced with a visual language of motion for both highly specific and emotionally expansive communication. Table A.3(a) in Appendix A illustrates the paths of the motion set.

4.2.4 Motion attributes

We replaced Curviness, Shape, SharpChange, and ObtuseChange attributes with the following two attributes:

- Fluidity (Fluidity): smooth, jerky, or combined.
- Shape (Shape): straight, angular, curvy, or combined. [1]

We note that fluidity can be considered as a combination of acceleration/deceleration and speed, and is closely related to the shape of the trajectory. The intention behind introducing this new attribute, while still keeping the related attributes was to examine which aspects of fluidity (if any) might prove influential.

In addition, we parameterized the emotional contents of mocap motions using the 3 dimensions of emotional classification advocated by Smith and Louis and according to the instructions given to the performers (in other words, the emotion they were supposed to enact). As a result, the Emotion attribute was replaced by:

- Valence/Pleasantness (Valence): positive, negative, abstract[2]
- Arousal (Arousal): active or non-active
- Dominance (Dominance): dominant or vulnerable

We note that these attributes are all nominal; therefore, we used a simple distance metric by assigning an ordinal value to each level in the factor (as shown in Table 4.2) and calculating the absolute difference between these ordinal values.

In addition to these three dimensions of emotion, the results were analyzed according to the following limited dimensions: Speed, Amplitude, Acceleration, Deceleration, Fluidity, and Shape. Speed, Amplitude, and Acceleration were found significant in the previous study and therefore chosen, and Deceleration was chosen due to the potential it might have when we considered the fact that the Acceleration was significant.

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[1] It is worth noting that the definition of Shape was changed as none of the new mocap motions was geometrically aligned with the previous definition of shape (spiral, circular, arch, etc.)

[2] such as importance

Attribute	Nominal value	Ordinal value
Fluidity	smooth	1
	jerky	-1
	combined	0
Shape	angular	-2
	straight	-1
	combined	0
	curvy	1
Valence	positive	1
	negative	-1
	abstract	0
Arousal	active	1
	non-active	-1
Dominance	dominant	1
	vulnerable	-1

Table 4.2: Assignment of ordinal values for nominal factors

4.2.5 Block design

32 motions produced 496 distinct combinations, which were presented to the participants in screens of 32 motions each, with 1 screen comprising 1 trial. Since 32 trials proved too onerous a task for a single participant, we balanced the combinations across 2 participants so that each participant processed 16 distinct source motions.

We used each motion as the source motion for the same number of times across all our participants. Every participant, however, saw all target motions, so every participant was exposed to all combinations. As a result this study was both a between participants (for source motion) and within participants (for comparison motions) design.

Statistically balanced randomizations were carefully designed to avoid first and second order effects, both with respect to the sets of combinations and the radial layout of the motions. Target motions were laid along three rings around the stimulus motion. As the distance between the stimulus motion and each target motion might affect the participants' judgment, the number of times each motion appeared on each ring was also balanced across all participants. A simple randomization was done to assign target motions a position inside the rings.[3] Sixteen trials were divided into four blocks, each consisting of four trials, for each

[3]Dr. Tom Loughin and his colleagues developed a statistically balanced randomization algorithm as described in Appendix C.

of our participants. These blocks were created only to allow participants an opportunity to take breaks during the experiment. The typical session for one participant lasted about 45 minutes.

4.2.6 Hypotheses

We had three hypotheses:

- Fluidity and smoothness of shape would be the most influential factors.
- Speed would be extremely important in associating motions.
- Participants would be able to distinguish positive and negative emotions.

We hypothesized that smooth, curvy motion should be easily distinguished from angular, jerky motion. Slow motion should also be differentiated from fast motion. Positive emotional motions such as happy and pleasure might look lively and energetic, while negative emotional motions such as sad and guilty might look dull and less energetic.

4.2.7 Participants

Ten SFU students were paid to participate in the experiment. All had normal or corrected-to-normal acuity and normal colour vision, which was stipulated as a precondition when recruiting participants. None had participated in previous experiments in this area. All were naive to the purpose and hypotheses motivating the study.

4.2.8 Results

Our first examination of the results led to the insight that our participants did not judge similarity and dissimilarity symmetrically: judgments of dissimilarity were more pronounced and there were more of them. For our purposes, either type of rating was informative. Figures 4.3 and 4.4 show similarity and difference rankings by the pairs of motions, where the size of the square indicates the rank. From this it was clear that motions performed for "similar" emotions did not evoke correspondingly strong similarity rankings. This indicated that participants' judgments were based primarily on low- to mid-level motion properties (our factors).

As our goal was to examine how judgments of similarity might be related to the identified factors (fluidity, speed, etc.), we used regression techniques to relate the participants' similarity rankings to the analytically derived similarity measurements. We used backwards elimination in a random coefficients model to accommodate both fixed effects from the controlled factors and random effects from the variation between participants. (We note that there was variability in the range of the scales that participants tended to use and will explain this variation when we revisit the results in the next experiment.)

Of the motion attributes that we examined, speed, amplitude, fluidity, and deceleration proved to be statistically significant: only fluidity and amplitude had a noticeable size of effect (Table 4.3 [4]).

First, as we expected, the fluidity of the motions had a strong effect on how similarly they were rated: overall the greater the difference in fluidity the lower the similarity. This effect did differ between participants: on average, 3 of the 10 showed a smaller effect, although still consistent with the trend. Amplitude, on the other hand, played a very strong role and showed no subject variation: again, the greater the difference in amplitude, the lower the similarity rating. Speed, while significant, surprisingly had less of an effect, and again varied between participants, with 1 participant showing it was not significant for him/her and others showing a small effect (in other words, there was a statistically significant correlation, but the difference it actually made was not substantial). We saw a similar result with respect to decelerations (although no participant variability). We note however the strong interactions between amplitude and speed, and between amplitude and decelerations. Speed made a greater difference when amplitudes were greater, as did decelerations. When we turned to the emotional axes, we discovered that the activation/arousal index was the only one which showed any correlation with similarity: a mismatch in activation correlated with a small decrease in similarity.

4.2.9 Discussion

These results were preliminary and difficult to generalize because they were limited to the motions of one particular performer; thus the relative strengths of the motion properties might reflect his/her predilections to expression as much as they reflected participants' criteria. However, they did shed some initial light on what might be usable motion attributes

[4] some participant variability, although not enough to negate the significance.

Factor	Significance	Estimated Effect
Fluidity	F(1, 9) = 26.47, p =.0006	-0.37
Amplitude	F(1, 2924) = 21.02, p =.0143	-0.33
Deceleration	F(1, 4924,) = 17.55, p < .0001	-0.16
Speed	F(1, 9) = 9.81, p = .012	-0.16
Arousal	F(1, 4924) = 27.66, p < .0001	-0.16
Amplitude*Speed	F(1, 4924) = 4.13, p = .04	-0.57
Amplitude*Deceleration	F(1, 4924) = 10.19,p = .0014	1.45

Table 4.3: Significant effects (Experiment 1A)

to consider for further interpretative investigation in these conditions. Recall that we were looking at very small, short motions. Given that as pattern recognizers we are primed to detect anomalies, it seems sensible that people are more attuned to discrepancies than similarities, and this may explain why we had stronger dissimilarity ratings than the inverses.

That several factors remain in the model showed that people did not rely on any single property to judge similarity. However, the results suggested at least two primary candidates for distinguishing these small animate motions: fluidity and scale (amplitude). These results partially confirmed our first hypothesis: fluidity, at least the coarse classification we used, proved to be the strongest effect. The associated smoothness of shape had no effect, perhaps subsumed by the larger effect of fluid or jerky motion. Speed, on the other hand, proved far less effective than we anticipated, refuting our second hypothesis. It seemed that where speed or deceleration mildly mattered, they were overshadowed by this larger quality of fluidity. We were also surprised by the asymmetry between acceleration and deceleration.

In retrospect the interactions between speed and amplitude, and deceleration and amplitude, were not surprising: the greater the motion extent, the easier it is to perceive differences in both. This reintroduced the whole concept of what amplitude meant in this smaller scale. There were two contributing aspects: the degree in which different motions used amplitude (in other words, the tendency of the performer to rely on amplitude as an expressive mechanism) and the inherent perceptibility. We had, in essence, a small canvas on which to paint these motion effects, and so the extent to which a motion covered this space was very perceptually apparent.

It may be that the nuances of speed and shape need to be mapped onto more specific measures related to fluidity that are perceptible in these small spaces. In the next experiment, we will revisit this data using several measures of trajectory path to explore fluidity,

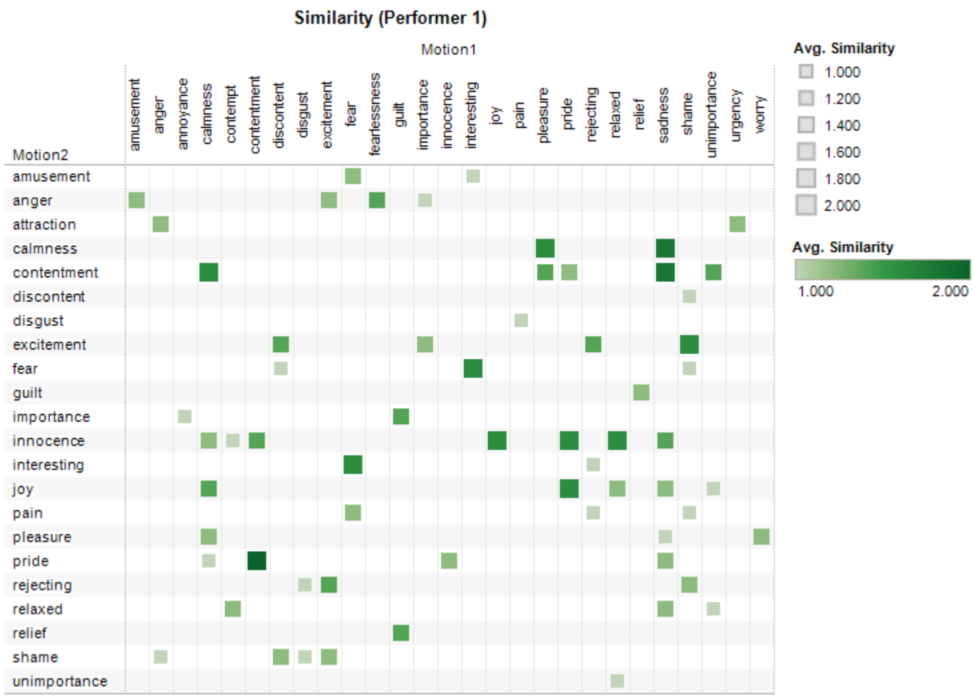


Figure 4.3: Mean similarity ratings for values greater than or equal to 1 (Performer 1).

including self-intersections, directional changes and angular turns. We anticipated these measures might help us further explore distinguishing characteristics of emotional motions.

It was also apparent that the intensity of an emotion (at least for this single performer set) could be communicated by these small motions to some small degree. We recall that we were not yet looking for definitively robust mapping of a particular motion attribute to specific emotional meaning: rather, we were seeking to further our understanding of what is possible in this design space and attempting to form a framework that is both computationally feasible (uses appropriate metrics) and visually interesting (provides enough scope for affect that it is useful). The fact that fluidity, amplitude and to a lesser extent, speed appeared viable dimensions pointed us to extensive future work in exploring how these might affect interpretation of motions generated using them.

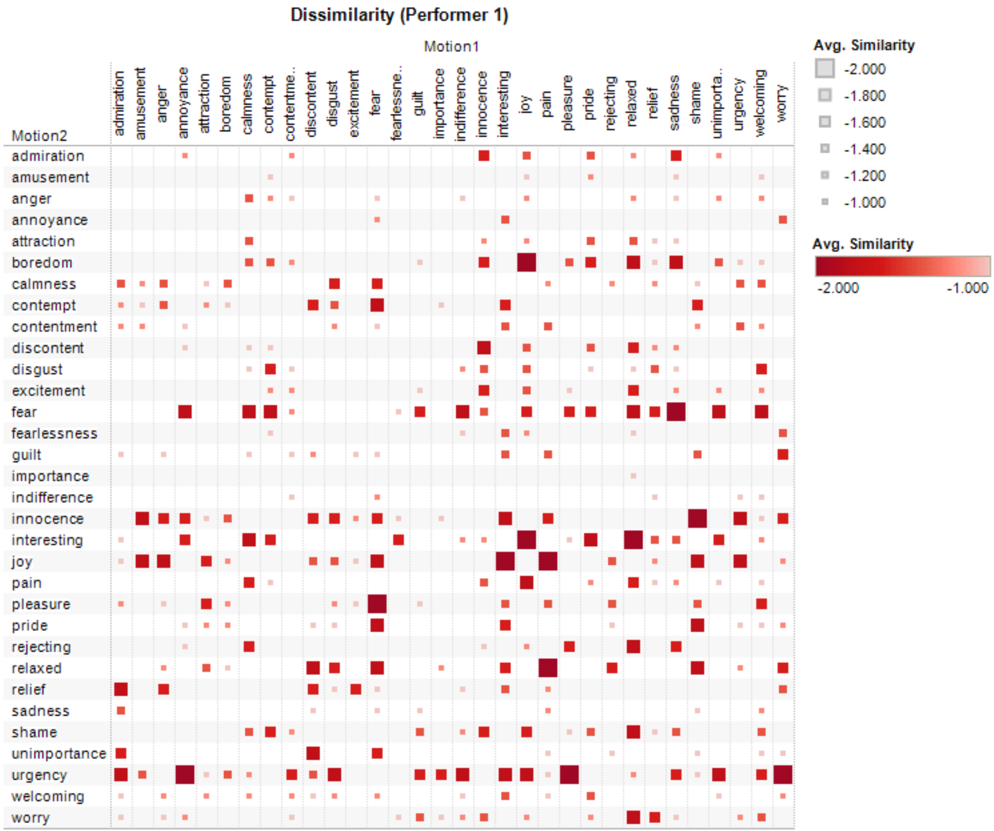


Figure 4.4: Mean difference ratings for values greater than or equal to 1 (Performer 1).

4.3 Experiment 1B

4.3.1 Goal of study

Experiment 1B was designed to be a control experiment for Experiment 1A. We used the exact same experimental design on two different motion data sets obtained from different performers. The goal of this experiment was to verify the results of Experiment 1A by testing whether they were performer dependent. That is, we were trying to verifying whether the relationship between the measured characteristic of the similarity between two motions and the perceived similarity by a participant may vary from performer to performer. Also, Experiment 1A suggested that the participants tended to judge similarity based on different criteria, which needed to be explained. With help of a professional statistician, we hoped to establish a method for effectively analyzing such complex data.

4.3.2 Motions

Experiment 1B used two different motion data sets obtained from Performer 2, the regular, unspecialized expressive person with no formal movement training, and Performer 3, the person with dancing and acting skills. Table A.3(b) and (c) in Appendix A illustrates the paths of these motion sets.

4.3.3 Additional motion attributes

Prior to the Experiment 1B, we increased the analytical classification of the generated motions by adding direction and trajectory metrics.

- Direction (Direction): diagonal, horizontal, vertical, or combination
- Vertical position (VerticalPosition): top, center, or bottom
- Horizontal position (HorizontalPosition): left, center, or right

As we captured more movements and the motion database grew, we noticed that unlike algorithmically generated motions, captured motions don't necessarily move around the center of the image. Hence, we suspected that the general area in which motion moves might also be affecting participants' judgments. SelfIntersection, ObtuseChange, and SharpChange were once again included to explain the information in trajectories that the new Shape might be missing.

4.3.4 Hypotheses

We had two hypotheses about this experiment.

- The results would suggest some attributes that are consistently important across different performers.
- An overall effect of fluidity and amplitude would again be noticeable.
- There would be a lot of variability among different performers and/or participants with regards to emotional attributes.

4.3.5 Participants

We recruited twelve participants for Experiment 1B. They were evenly divided into two groups; one group saw the motions obtained from Performer 2, and the other group saw the motions obtained from Performer 3. Each motion was shown as a stimulus motion for at least three times across six participants. The exact same block design as Experiment 1A was used.

4.3.6 Modeling procedure

Throughout Experiment 1A and 1B, we obtained three different sets of results from three participant groups where each group rated similarity between motions obtained from one particular performer. We performed mixed-effects regression analysis on these three sets of data as a whole.[5]

The response variable (the similarity scores) were entered into a mixed-effects regression model with explanatory variables (motion attributes and some interactions between pairs of these attributes). All explanatory variables were entered as *fixed effects* (FIXED) and also as *random effects* in the following two levels of a hierarchy:

- RANDOM-PERFORMER (top level): variability among performers with respect to the relationships between similarity of motions and the perceived similarity.
- RANDOM-PARTICIPANT (second level): variability among participants with respect to how the different variables explain their perceptions of similarity.

The implications of the RANDOM-PERFORMER effects was that the relationship between some measured characteristic of the similarity of two motions and the perceived similarity by a participant might vary from performer to performer, while the implications of the RANDOM-PARTICIPANT was that the relationship between measured characteristics of a motion and the participants' perception of similarity might vary from participant to participant. That is, participants might judge similarity based on different criteria.

The model reduction took place in the following steps. First, it was investigated whether variables could be completely removed from the model in all forms in the following order: RANDOM-PARTICIPANT, RANDOM-PERFORMER, and finally FIXED. These steps were

[5] The analysis was suggested and conducted by Dr. Tom Loughin [28].

repeated in sequence until no further variable reductions resulted in a better model.[6] The last model was considered the final model for purposes of interpretation of relationships between the motion characteristics and the similarity scores.

4.3.7 Results

Table 4.4 shows the final model, showing which variable had fixed and/or random effects. Variables such as Acceleration, Deceleration, and Dominance dropped in the very first step. They were found to have no important effect on similarity, and the relationship between them and the similarity was not dependent on the performer or the participant.

First, Figure 4.5 shows the slopes for all fixed effect variables in the model and their corresponding 95% confidence intervals (calculated taking into account any random effects that might influence the variability of this slope). A narrow confidence interval that does not cross zero (such as Amplitude, Shape, and Direction) indicates that the variable is clearly important in explaining perceived similarity. [7] The interval for Speed and Speed * Amplitude were wide, but their effects were very high.

Next, Figure 4.6 shows the smallest and largest slope among all random effect levels in the model. This gives an impression of the amount of variability that was present among some participants and performers. It's clear that Speed, Fluidity, and VerticalPosition had a lot of variability.

4.3.8 Discussion

Overall, we found that Speed, Amplitude, Shape, and Direction were all significant and had noticeable effects on the similarity judgment. Especially Speed had the strongest effect, showing that it was the most dominant variable. Shape, Direction and Speed * Amplitude were the only three factors that were neither performer nor participant dependent, suggesting that these attributes may be universally important. VerticalPosition also had a relatively strong effect; however, there were a lot of variability in slope among both performers and participants. Fluidity and Arousal were both found significant in Experiment 1A, yet they

[6] The modeling was done using the corrected version of Akaike's Information Criterion (AICc) as a modeling criterion [8].

[7] For any motion characteristics left in the fixed part of the model, the partial slope of the relationship between mean similarity score and that characteristic was computed, while simultaneously considering all other variables in the model [35].

Characteristic (similarity)	FIXED	RANDOM-PERFORMER	RANDOM-PARTICIPANT
Speed	✓		✓
Amplitude	✓		✓
Valence		✓	✓
Arousal		✓	
Fluidity		✓	✓
Shape	✓		
ObtuseChange	✓	✓	
SharpChange	✓	✓	✓
SelfIntersection	✓		✓
Direction	✓		
HorizontalPosition	✓		✓
VerticalPosition	✓	✓	✓
Speed * Amplitude	✓		
Direction * HorizontalPosition	✓	✓	
Shape * ObtuseChange	✓		
Amplitude * SelfIntersection	✓		

Table 4.4: The final model and their fixed and random effects

depended on the performer (Performer 1) and therefore were not found important. This did not support our hypothesis. This could be because conductors are trained to use these two attributes to convey meaningful information. Variables such as Acceleration and Deceleration were completely ignored, which could be due to the fact that the size of motion was too small to notice the changes in speed. The relationship between emotional contents of motion and the similarity was dependent on the performer or the participant, which supported our hypothesis.

4.4 Summary

The three experiments reported in this chapter suggested that the factors such as Speed, Amplitude, Shape, and Direction were highly reliable terms in distinguishing one motion from another. The relationship between the similarity judgment and some of these variables were neither performer nor participant dependent, meaning that when given two motions whose characteristics are direct opposite with each other with regards to these variables, a viewer might get two completely different impressions.

Our next study will investigate how these results can be extended to more complex

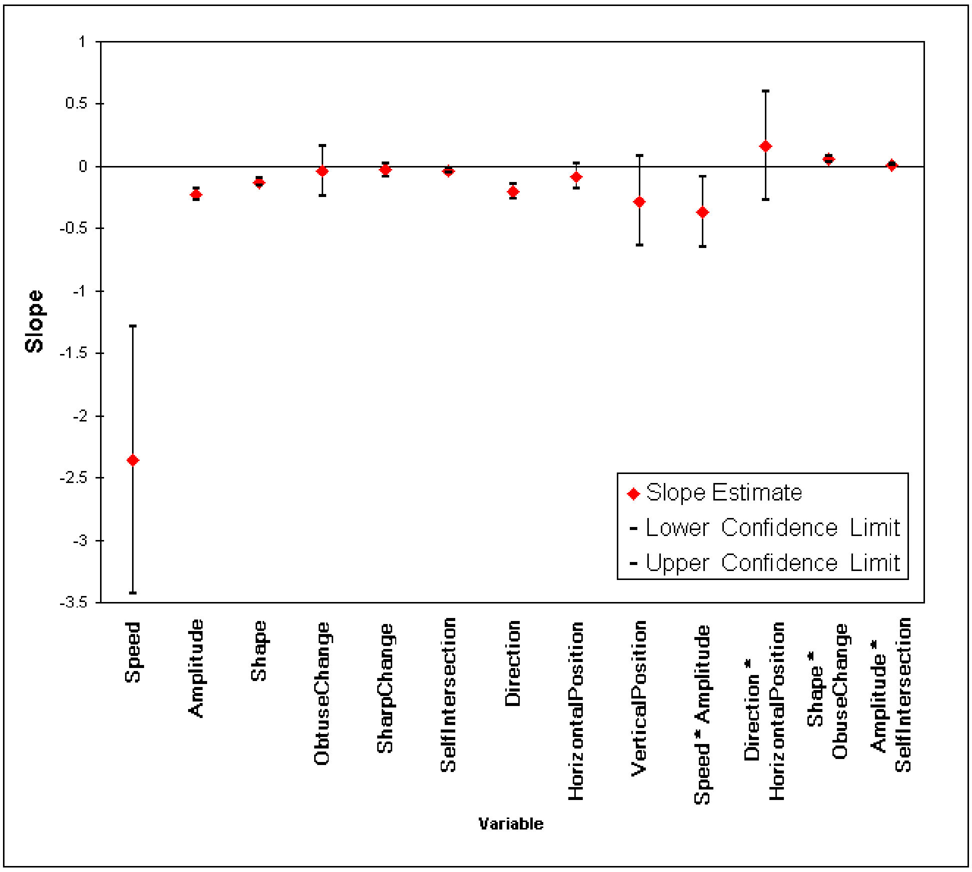


Figure 4.5: Estimated regression coefficients and confidence interval

perceptual effects and impressions that may be usefully manipulated as variables in visual interface applications. Now that we identified candidates - and candidate combinations - of useful attributes for motion distinction, we will use them to select particular motions for a subsequent study of interpretation, where participants will use a variety of interpretative methods to describe the motions.

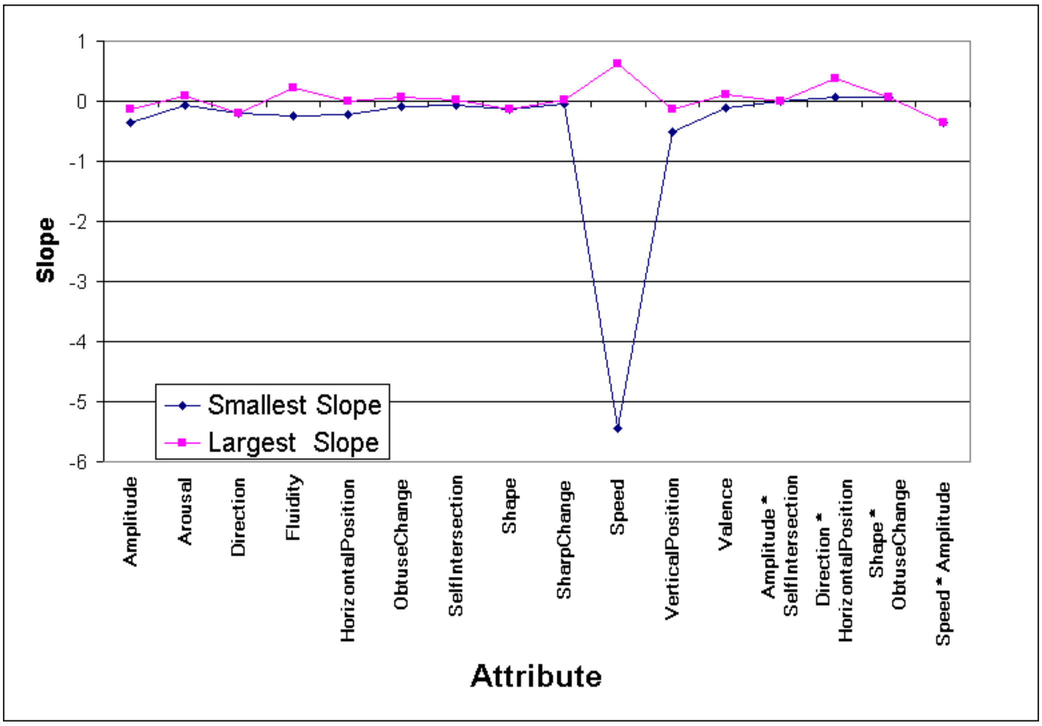


Figure 4.6: Smallest and largest slope among all random effects for each variable in the model

Chapter 5

Interpretation

5.1 Goal of study

In the previous chapter, we determined which motion attributes contributed towards distinguishing one motion from another. The experiment presented here was designed to explore the potential of simple motion to create affect. Our ultimate goal was to determine if, and how, a particular impression or emotion could be evoked from a small, abstract motion. This study was motivated by the following research questions:

- Are there common interpretations or classifications about a particular motion?
- Is there agreement on which motions correspond to a particular interpretation?
- What are the properties of each motion that influence a common interpretation? In other words, what contributes to motions having that effect?

5.2 Task and method

Participants sat in front of a standard 20" computer monitor of 1280x1024 resolution and were presented with a sequence of 37 motions for each of which they ranked the interpretative affect. Each motion comprised one trial. Participants were asked to rank the motions against 24 specific affective ratings (the dependent measures), listed in Table 5.1. These ratings included basic emotions (from Ekman), and more diffuse "atmospheric" effects. We added a third type of impression - termed "abstract" - to expand the scope of attributes we might want to represent in different applications (such as notifications).

Figure 5.1 shows the experiment screen for a trial. Motions were rendered with a small unicolour sphere. All displays were constructed using JOGL (3D Java). We placed 14 slider bars directly below the motion, distributed into three columns; 5 slider bars were placed on the left column, another 5 slider bars were placed on the middle column, and the remaining slider bars were placed on the right column. The sliders in the middle and left columns implemented semantic differential scales in that each end of the slider represented one extreme of an antonym pair (such as "happy" and "sad"). This made the interface much less cluttered and also saved the participants from doing redundant evaluations; we assumed that certain judgments excluded others (for example, if a motion looks like happy, it should not look sad at the same time). On the other hand, each of the 4 slider bars on the right column only had a label on one side, representing judgments that had no easy antonyms in our interpretation set and thus were set as single Likert-like scales. All values for each scale ran from 0 to 5, so that in the semantic differential slider 0 was set in the middle.

The trial began when the participant pressed the "Start" (underneath the motion) button. We instructed participants to move the slider towards any feeling or impression they thought the motion communicated. The rating depended on the strength of the expression, ranging from 0 to 5 by increments of 1. Not moving the slider (a "0" rating) meant no expressive effect. They could then move as many sliders as they wished: they were told that no rating HAD to be entered, so that if there were a motion that evoked no impression the participant could simply leave all the sliders at 0 and move to the next trial. We also considered the rating to be 0 if the rating for the opposite expression was chosen to be greater than 0. For instance, if the rating for happy-sad was 2 towards sad, the rating for sad was 2, and the rating for happy would be 0 instead of -2.

Pressing the "Finish" button loaded a new motion to evaluate. Throughout the experiment, they could replay the animation or change the rating as many times as they wanted, before pressing the Finish button to go to the next trial. The duration of each motion was five seconds, and the motion repeated itself thereafter in a loop. They were given unlimited practice time to evaluate 2 motions in advance, to get familiar with all of the expressions to evaluate.

Emotions	
happy...sad	angry
pleasant...painful	fearful
disgusted...attracted	proud
amusing...annoying	relieved
Atmospheric	"Abstract"
reassuring...threatening	important...unimportant
welcoming...rejecting	urgent...relaxed
exciting...calming	interesting...boring

Table 5.1: Interpretative scales

5.3 Motion data

Previous studies reported in Chapter 4 have established that amplitude, speed, direction, and shape were key factors in distinguishing one motion from another. Out of over 100 motions we had generated and collected, we chose 37 motions such that each of the motions had only one (or at most a few) of these motion attributes present dominantly while the other attributes were average. Selecting motions this way helped us identify which of the motion attributes was a true indicator for a certain expression.

The resulting motion data set included three types of motions: 24 expressive movements obtained from 3 different performers, 3 motions derived from Tagiuri's hand-drawn trajectories, and 5 algorithmically generated motions in two different speeds (a total of 10 algorithmically generated motions). The trajectory paths of these selected motions are shown in Table A.4 in Appendix A. Mixing multiple sources of motion allowed us to compare the effects of encoded emotional contents by the performers against the reported impressions of Tagiuri's trajectories and simple mechanical movements that are commonly used for motion icons on a display.

It is worth noting that the selection of the expressive motions (captured while performers enacted certain expressions) was completely detached from the selection of the rating criteria (presented to participants as options for feedback). Although some of the terms (describing the motions and the rating criteria) overlap, it is important to remember that the main purpose of this study was not to examine how accurately the viewer's perception matched what the performer intended. We used the following naming conventions to address this confusion: all of the mocap motion names are prepended by *mocap-* (i.e. *mocap-joy*) while all of the algorithmically generated motion names are appended by either *-slow* or *-fast*,

Figure 5.1: Experiment 2 screen capture

depending on the speed (i.e. *spiral-slow*).

Building on previous work, the attributes that we investigate in this study are: Speed, Amplitude, Acceleration, Deceleration, Direction, Fluidity, VerticalPosition, HorizontalPosition, Shape, SelfIntersection, SharpChange, ObtuseChange, Valence, Arousal, and Dominance.

Each motion was mapped to a simple dot 10 pixels in diameter. Finally, we rendered the motions in 2 frame sizes: an image of size 125x125 pixels (SMALL motion) or 250x250 pixels (BIG motion).

5.4 Block design

One group of participants saw only the BIG motion set; a second group saw only the SMALL motion set. All other conditions were identical across both groups. Each participant saw and evaluated all of the motions exactly once in a randomized order. This made 37 trials for each participant. 37 trials were then divided into 4 blocks (each block represents a set of unrelated motions to be evaluated), where the first three blocks consisted of 9 trials, and the last block consisted of 10 trials. These blocks were created only to allow participants an opportunity to take breaks during the experiment. The typical session for one participant lasted about 45 minutes.

5.5 Hypotheses

We had five hypotheses about this study.

- Speed and amplitude would be important factors; fast and/or large motion would be perceived as energetic, active motion, while slow and/or small would elicit low intensity.
- Smooth motion would be perceived as positive expressions such as happy, while jerky motion would elicit a negative impression.
- Curvy motion would also elicit positive impressions, while angular motion would not.
- Motion which moves mainly on the upper part of the image would be perceived as positive, and vice versa.
- Two sizes of motion sets should give similar results, except with regards to amplitude if it was found influential as described in the first hypothesis.

5.6 Participants

Twenty-four SFU students and alumni were paid to participate. They were evenly divided into the two groups. All had normal or corrected-to-normal acuity and normal colour vision, which was stipulated as a precondition when recruiting participants. All were naive to the purpose and hypotheses motivating the study. They spanned a variety of ethnic and cultural backgrounds.

5.7 Results

Our first examination of the results led to the insight that our participants did not differentiate some of the rating terms; for example, when a particular motion was ranked as "happy" by a participant, it was also ranked as other positive terms such as "welcoming" by the same participant. We performed a Principal Component Analysis (PCA) to take orthogonal factors out of possibly correlated responses and ran linear regression analyses on each factor for BIG and SMALL motions separately. We used PCA for 2 reasons: we wanted to simplify the results set by extracting new factors (main groups of responses) that could explain as much of the variability in interpretations as possible, and we then wanted to see if there were correlations with the motion attributes previously identified as potentially influential. For both the BIG and SMALL motions, 3 main factors encompassed the largest share of the variability.

Figures 5.2 (BIG) and 5.3 (SMALL) show the plots of the eigenvalues that indicate the contribution of each factor, clearly suggesting the 3-factor solution for both SMALL and BIG motions (Tables E.1 and E.2 in Appendix E show eigenvalues of the correlation matrix). Figures 5.4 and 5.5 show the percentage weights of each original variable for each factor. We note that these factors explained about 50% of the total variability for the BIG motions and 40% for the SMALL motions.

We categorized the original measures into these three new factors and named them appropriately so that we could see clear patterns across different sizes of motions: we named them POSITIVE, NEGATIVE and CALM (prefaced by motion size, as shown in Tables E.3 and E.4 in Appendix E. The bottom row of each table shows how much of the variance each factor accounted for).

The first pair (BIG-POSITIVE and SMALL-POSITIVE) was highly correlated with positive terms such as happy, pleasant, attracted, amusing, welcoming, exciting, and interesting, while the second pair (BIG-NEGATIVE and SMALL-NEGATIVE) was highly correlated with negative terms such as angry, painful, threatening, disgusted, rejecting, urgent, fearful, and annoying. The only differences were that fearful is not strongly associated with SMALL-NEGATIVE as it was in BIG-NEGATIVE. The third pair (BIG-CALM and SMALL-CALM) was correlated with terms whose intensity was low such as reassuring, calming, unimportant, relax, boring, and relieved. Sad was strongly associated with BIG-CALM but not as much with SMALL-CALM.

5.7.1 BIG motion

Significant attributes and their coefficient estimates for the first factor (BIG-NEGATIVE factor), the second factor (BIG-POSITIVE factor), and the third factor (BIG-CALM factor)

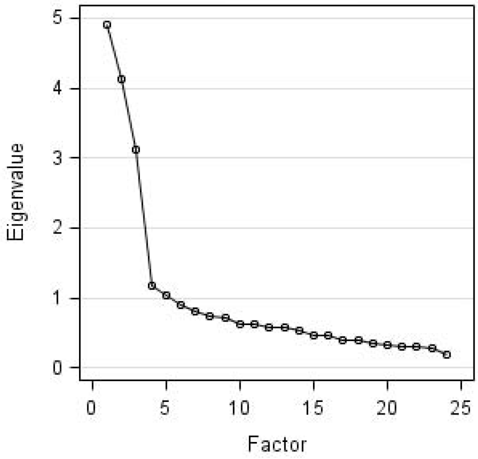


Figure 5.2: Factor contribution (BIG)

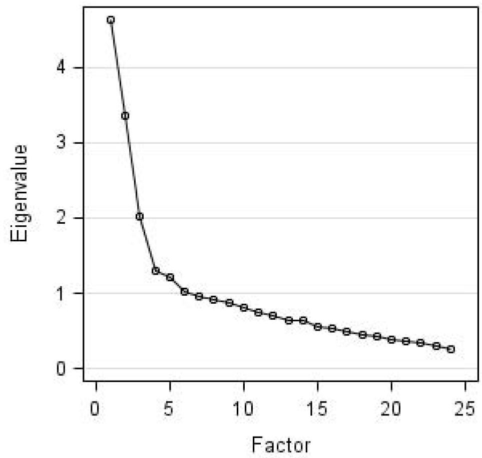


Figure 5.3: Factor contribution (SMALL)

are shown in Table 5.2, 5.3, and 5.4, respectively. In these tables, the attributes are sorted by the absolute values of the coefficient estimates. Some of the attributes were not significant (>.05) in the model, yet they were included, because the resulting model appeared to be the best by AICC, the primary modeling criterion we used. The coefficient estimates of such attributes are shown in parentheses.

What do these statistics tell us in practical terms? For the numeric attributes, such as Speed, when the coefficient estimate was a positive value for a certain factor (POSITIVE, NEGATIVE or CALM), the attribute was considered positively correlated with that factor (and its associated rating terms). For instance, high positive estimates (2.37 of Speed for BIG-NEGATIVE factor) indicates that faster the speed, the stronger the negative impression it conveys. For nominal attributes such as Shape, the coefficient estimates were separately calculated to show the effect of each variation (angular, straight, etc.) in the attribute; for example, the relatively high positive estimate (0.54 of angular for BIG-NEGATIVE factor) indicates that this shape elicited strong negative impression.

Overall, Speed, Fluidity, Acceleration, ObtuseChange, VerticalPosition, and Shape were found highly significant for the BIG-NEGATIVE factor, followed by HorizontalPosition, Amplitude, and Dominance. Dominance, Fluidity, ObtuseChange, and Speed were positively correlated, although Dominance didn't have a noticeable size effect. Acceleration was negatively correlated, and Amplitude was neutral. Angular (Shape), left (HorizontalPosition), and bottom (VerticalPosition) had relatively strong positive effects on the ratings, while

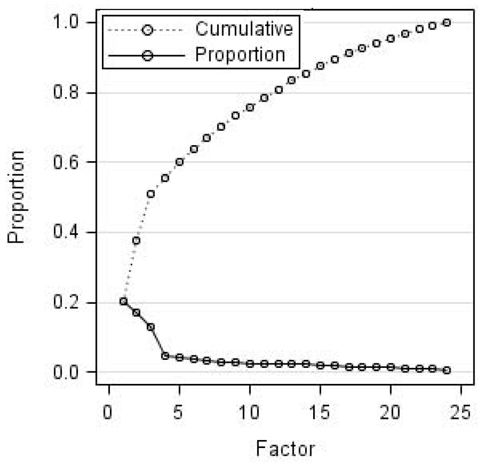


Figure 5.4: Variability accounted for by factor (BIG)

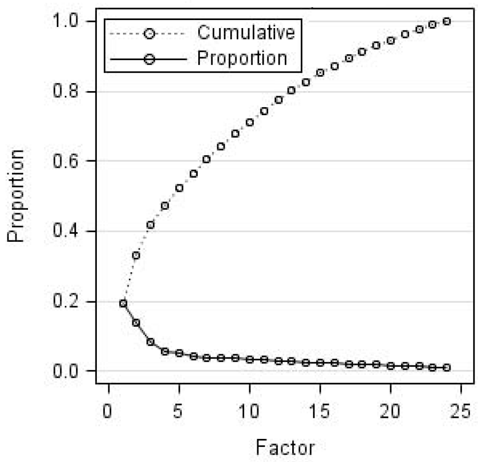


Figure 5.5: Variability accounted for by factor (SMALL)

curvy (Shape), right (HorizontalPosition), and top (VerticalPosition) had relatively strong negative correlations. The overall results suggested that the BIG motion tended to be rated as more negative when:

- The speed was faster.
- The trajectory had more obtuse directional changes.
- It mainly moved at the lower part of the image.
- It had less accelerations.
- The shape was angular and not curvier.
- The fluidity of the motion was smoother.
- It mainly moved on the left side of the image.
- The emotional encoding was dominant.

For the BIG-POSITIVE factor, Amplitude and Acceleration were strongly significant. Self-Intersection and SharpChange were also found significant, but they did not have noticeable effects. Only Speed had a relatively strong positive effect. It appeared that curvy motion also gave positive impression, while angular motion did not. Overall, the BIG motion tended to give more positive impressions when:

Attribute	Significance		Estimate
Speed	F(1, 394)=28.56, <.0001		2.39
Fluidity	F(1, 394)=8.64, 0.0035		0.31
Acceleration	F(1, 394)=12.01, 0.0006		-0.14
ObtuseChange	F(1, 394)=17.12, <.0001		0.11
Dominance	F(1, 394)=3.88, 0.0497		0.10
Amplitude	F(1, 394)=6.27, 0.0127		-0.09
Arousal	F(1, 394)=2.28, 0.1315		(-0.09)
Shape	F(3, 394)=11.41, <.0001	angular	0.54
		straight	0.01
		combined	-0.22
		curvy	-0.61
HorizontalPosition	F(2, 394)=6.72, 0.0013	left	0.38
		center	0.14
		right	-0.73
VerticalPosition	F(2, 394)=13.27, <.0001	bottom	0.44
		center	-0.26
		top	-0.39

Table 5.2: Significant effects (BIG-NEGATIVE)

- The speed was faster.
- The amplitude was larger.
- There were less accelerations.
- The trajectory was curvy and not angular.

For the BIG-CALM factor, Speed, Deceleration, Shape, and SharpChange were significant attributes; Speed had a relatively strong negative correlation with the factor, Deceleration had a small negative correlation, and others were neutral. Curvy motion had a positive effect, while angular gave a negative effect. We conclude that the BIG motion looked calmer when:

- The speed was slower.
- It had more decelerations.
- The trajectory was curvy.

Attribute	Significance		Estimate
Speed	F(1, 11)=1.27, 0.2838		(0.86)
Amplitude	F(1, 378)=12.59, 0.0004		0.14
Acceleration	F(1, 378)=9.11, 0.0027		-0.12
SelfIntersection	F(1, 378)=9.07, 0.0028		0.04
SharpChange	F(1, 11)=6.25, 0.0295		0.03
Shape	F(3, 378)=6.38, 0.0003	curvy	0.28
		combined	-0.03
		straight	-0.15
		angular	-0.28

Table 5.3: Significant effects (BIG-POSITIVE)

Attribute	Significance		Estimate
Speed	F(1, 390)=27.60, <.0001		-2.49
Deceleration	F(1, 390)=8.19, 0.0044		-0.13
Arousal	F(1, 390)=3.13, 0.0777		(-0.09)
SharpChange	F(1, 11)=5.57, 0.0379		-0.03
Shape	F(3, 390)=4.94, 0.0022	curvy	0.19
		straight	0.06
		angular	-0.10
		combined	-0.19

Table 5.4: Significant effects (BIG-CALM)

5.7.2 SMALL motion

Significant attributes and coefficient estimates for the first factor (SMALL-POSITIVE factor), the second factor (SMALL-CALM factor), and the third factor (SMALL-NEGATIVE factor) are shown in Tables 5.5, 5.6, and 5.7.

For the SMALL-POSITIVE factor, Shape and Valence were the most significant. Speed, VerticalPosition, and Direction were also found significant but not as significant as Shape and Valence. The table suggests that emotional encoding of pleasantness was positively correlated, which means that positive emotional motions were actually perceived as positive. Both curvy and angular (Shape) and top (VerticalPosition) had equal positive effects, while straight (Shape) and bottom (VerticalPosition) gave relatively strong negative effects. In summary, the SMALL motion was perceived more positive when:

- The trajectory was either curvy or angular and not straight*[1].
- The emotional encoding of pleasantness was positive.
- It moved vertically or horizontally and not diagonally.
- It moved mainly at the upper part of the image and not the lower part of the image.

Attribute	Significance		Estimate
Valence	F(1, 361)=9.16, 0.0026		0.15
Arousal	F(1, 11)=2.24, 0.1625		(0.11)
Dominance	F(1, 361)=2.43, 0.1202		(0.08)
SharpChange	F(1, 11)=1.99, 0.1858		(0.02)
Speed	F(1, 11)=5.25, 0.0427		0.02
Shape	F(3, 361)=12.89, <.0001	angular	0.20
		curvy	0.20
		combined	-0.14
		straight	-0.49
Direction	F(4, 361)=2.86, 0.0236	vertical	0.15
		horizontal	0.10
		ver-hrz	-0.11
		diagonal	-0.17
		hrz-ver	-0.26
VerticalPosition	F(2, 361)=4.46, 0.0122	top	0.14
		center	0.00
		bottom	-0.31

Table 5.5: Significant effects (SMALL-POSITIVE)

Speed was found incredibly important for the SMALL-CALM factor. Shape, ObtuseChange, and VerticalPosition were also significant but not as much as Speed. Speed was negatively correlated with the factor, hence slower motions were perceived as calm. Straight and curvy (Shape) had positive effects, while angular (Shape) as well as motions bottom (VerticalPosition) had relatively strong negative effects. Top (VerticalPosition) also had a small negative effect, but not as much as bottom (VerticalPosition). Overall, the SMALL motion was likely to be perceived calmer when:

- The speed was slower*.

[1] '*' indicates that the same statement was true for the same factor of the BIG motion.

- The shape was curvy or straight and not angular*.
- There were less obtuse directional changes.
- It did NOT move at the bottom part of the image.

Attribute	Significance		Estimate
Speed	F(1, 383)=39.83, <.0001		-2.90
Arousal	F(1, 383)=3.64, 0.0570		(-0.12)
Dominance	F(1, 383)=3.10, 0.0791		(-0.09)
ObtuseChange	F(1, 383)=7.58, 0.0062		-0.08
Fluidity	F(1, 11)=0.38, 0.5506		(-0.07)
Shape	F(3, 383)=7.66, <.0001	straight	0.19
		curvy	0.17
		combined	-0.36
		angular	-0.40
Direction	F(4, 383)=2.21, 0.0670	horizontal	(0.09)
		ver-hrz	(-0.01)
		diagonal	(-0.14)
		hrz-ver	(-0.19)
		vertical	(-0.26)
VerticalPosition	F(2, 383)=4.72, 0.0095	center	0.08
		top	-0.12
		bottom	-0.26

Table 5.6: Significant effects (SMALL-CALM)

For the SMALL-NEGATIVE factor, Speed, ObtuseChange, Shape, HorizontalPosition and VerticalPosition were found highly significant. Acceleration, and Arousal were also found significant. Among all of the significant attributes, Speed appeared to have a relatively strong positive correlation with the factor. Fluidity also had a strong positive correlation although it was not found significant. Acceleration and ObtuseChange were also positively correlated with the factor, but not as much as Speed and Fluidity. Angular had a positive effect, while curvy (Shape) had a relatively strong negative effect. Left (HorizontalPosition) and bottom (VerticalPosition) were negative, while right and top were definitely not. In summary, the SMALL motion was likely to be perceived negative when:

- The speed was faster*.
- The trajectory was smoother*.

- It accelerated more.
- The trajectory had more obtuse directional changes*.
- The trajectory was NOT curvy but angular*.
- It did NOT move on the right side of the image but the left side*.
- It did NOT move on the upper part of the image but the lower part*.

Attribute	Significance		Estimate
Speed	F(1, 11)=22.03, 0.0007		3.30
Fluidity	F(1, 11)=4.07, 0.0687		(0.28)
Acceleration	F(1, 11)=13.42, 0.0037		0.18
Arousal	F(1, 362)=6.10, 0.0140		-0.15
ObtuseChange	F(1, 362)=18.99, <.0001		0.12
Deceleration	F(1, 362)=3.31, 0.0695		(-0.09)
Shape	F(3, 362)=9.97, <.0001	angular	0.20
		straight	-0.01
		combined	-0.34
		curvy	-0.73
HorizontalPosition	F(2, 362)=9.15, 0.0001	left	0.28
		center	0.15
		right	-1.09
VerticalPosition	F(2, 362)=18.18, <.0001	bottom	0.39
		center	-0.40
		top	-0.64

Table 5.7: Significant effects (SMALL-NEGATIVE)

Finally, visualization of the results are provided in Figures E.1, E.2, E.3, E.4, E.5, and E.6 in Appendix E, for each factor. Each figure shows mean ratings on motions (each described in terms of Shape and Speed) evaluated by the participants. It is clear that each factor had certain trends; slow, curvy motions were rated high for the BIG-CALM expressions, while fast, curvy motions were rated high for the SMALL-POSITIVE expressions. Moreover, although the purpose of this study was not to examine how accurately the viewers matched what the performer intended, it's interesting to see how closely they often matched; the motion *mocap-calmness* was rated the highest for "relaxed" and "calm" (SMALL-CALM), the motion *mocap-urgent* was rated the highest for "urgent" (BIG-NEGATIVE), and the motion *mocap-joy* was rated the second highest for "happy" (BIG-POSITIVE).

5.8 Discussion

The PCA analysis reduced the dimensionality of the data into a smaller number of uncorrelated factors. Two separate analyses for different motion sizes resulted in similar solutions; we found three identical important factors for each motion size: POSITIVE, NEGATIVE, and CALM.

The results we obtained from the regression analyses also showed many resemblances between smaller and bigger motions. First of all, speed and shape were highly significant through all of the factors and motion sizes. In fact, speed was the most significant attribute for both CALM and NEGATIVE factors regardless of the size of motion. The CALM factors for both SMALL and BIG were found to be associated with slower motions, which partly supported our hypothesis.

The NEGATIVE factor had many significant attributes, and the results exactly matched between different motion sizes. The NEGATIVE factor was associated with faster, angular, smooth motion which had more obtuse directional changes and mainly moved at the lower-left side of the image. This and the fact that the SMALL-POSITIVE was positively correlated with the upper side motion suggested the vertical positioning of motion affected the pleasantness of the motion. This supported our hypothesis. The position aspect is particularly interesting, because we often use expressions such as “feeling down” or “feeling low” to express our negative emotional states.

On the other hand, the POSITIVE and CALM factors had fewer significant attributes compared to the NEGATIVE factors. Regardless of the size of motion, both CALM and POSITIVE motions were curvier and not angular, which also supported our hypothesis. Fluidity had an effect only on the BIG-NEGATIVE motion, and to our surprise, the smoother the fluidity, more negative the motion looked. This did not match our hypothesis.

Large amplitude was found to be positively associated with the BIG-POSITIVE factor, but not associated with the SMALL-POSITIVE. In fact, amplitude was never found significant for the small motion factors, although it was found highly important in grouping similar motions using the same size image.

All of the emotional classifications (of the mocap motions) were found significant for at least one factor, which encouraged our speculation that emotions could be coded by grossly captured arm movements. Although rarely found significant, arousal was consistently included to improve the model. Dominance-vulnerability was positively correlated with

BIG-NEGATIVE, which made sense considering this factor was associated with dominant expressions such as angry and threatening. The exaggeration of each dimension might help us correctly represent certain emotions without being misinterpreted as other similar emotions.

We anticipate this will lead to a set of guidelines for the design and use of small affective motions: algorithmic techniques for reliably conveying affect, and a validated framework for the expressive scope of such small motions in both focused and ambient visualizations.

Finally it is worth noting that some of the very tight pairings between the performer's intention and the participants' rating (such as the one between the *mocap-urgent* and the "urgent" rating) took place for the conductor's motions. This gives some incentive to choose trained performers in the future studies to analyze the accuracy of perception of motions from various performers.

5.9 Summary

This study is part of a larger research agenda that explores how the modality of motion and animation can be exploited to convey the increasingly nuanced and sophisticated aspects of meaning required by affective user interfaces and visual environments. We examined how 37 distinctive motions were ranked with respect to 24 possible interpretations. We found that while there was variation within individual interpretations, they clustered into three major type of response: positive (happy, pleasant, amusing, welcoming, exciting, interesting); negative (including painful, threatening, disgusted, urgent, angry, and fearful) and calm (including sad, unimportant, relaxed and boring). Certain attributes of the motions were strongly influential in affecting how a motion was rated in these three categories, including shape, position, and speed.

Finally, our results point to the potential and the pitfalls of enhancing affect with motion. If we know that certain motions have a calming effect we may want to ensure those are present on an oncologists' website. On the other hard, we certainly do not want those same calming cues on a monitor in a hockey team's dressing room! The results of this study may be applied to a variety of applications, including notification interfaces, social computing and visualization.

Chapter 6

Conclusions and Future Work

In this chapter, we will revisit our research questions and provide a summary of the results along with the implication and limitations. We will also establish some empirically validated principles and guidelines on the design of affective motion coding.

6.1 Summary of research

Motion has been shown to be a powerful conduit of visual information. It is also a rich means of affective communication. However, there is little research on what aspects of the motion actually contribute most effectively to a desired impression. The goal of our research was to understand and characterize the dominant attributes that may enable us to encode meaning into motion. We first approached this goal by determining what motion attributes, or combinations thereof, might differentiate motions. The experimental results suggested that speed, amplitude, direction, and shape were the most important criteria. These results reduced the dimensionality of motion parameter space, to be taken into consideration, when selecting a set of unique motions for the subsequent study in which people actually evaluated the affective contents of motion. In the study, we were interested in analyzing how certain attributes of the motions were strongly influential in affecting how a motion was rated. The results revealed that variables such as shape and speed were by far the most influential attributes in affective communication, while other variables such as amplitude and position could also be useful depending on the desired impression.

6.1.1 Design implications and limitations

We deliberately made our study context-free (detached from any specific application or set of visual semantics) to explore the ability to elicit an interpretation with no other cues. These results do suggest that simple, small, abstract motions can be used to add meaning into a visual environment. Particularly, we are interested in developing a small tool set of animation techniques for interaction designers and game designers to explore both animated icons and motion textures. Using guidelines listed in the next section, we can apply motion directly to a particular object (such as an icon) to convey properties associated with that object. For example, "happy" motion might be generated using the guidelines for encoding positive motions. Appendix F describes how we generated "happy" and "sad" flags in the attached DVD to show how the country is doing at the Olympic Games.

Our findings are preliminary, of course, in that they have not been tested in applied contexts. We note that they do not explain each individual interpretation we examined in the study or other interpretations that can be useful in a display environment. Rather, our results can be used as simple guidelines to convey (or avoid) certain types of affect.

Another disclaimer worth mentioning, when looking at the conclusion from our research has to do with the impact of culture. Some motion attributes and their interpretations may be universal, but some may be vulnerable to cultural effect. For example, almost all participants attached equal importance to attributes like shape and direction when judging similarity of two given motions, however such universal appeal was not observed for other attributes like fluidity. We wish to attribute this unexplained difference in perception to the variations in cultural backgrounds of our participants. Further studies might explore the significance of this effect; however, it is worth noting that our research was primarily focused on realizing universal motion attributes, rather than attributes which have higher dependence on culture. A similar case can also be made for variations among participants (and their impact on perception) in gender, profession, etc.

6.2 Guidelines for motion-based affective coding

The results from our studies reported in this thesis suggested the following guidelines on the design of affective motion coding.

- Motion amplitude can be small.

- Motion can be represented as simply as a single dot.
- Differences in speed, direction, amplitude, and/or shape can be used to distinguish one motion from another.
- Shape, speed, and positioning of motion strongly contribute to an overall impression of motion.
- Abstract motion derived from motion captured arm movements carry rich expressive contents, which can be explained by three dimensions of emotion: valence, arousal, and dominance-vulnerability.
- Slow, curvy motion can give a calm impression.
- Fast, angular motion which moves on the lower-left part of the image can be used to elicit a negative impression.
- Large, curvy motion can give a positive impression, but the amplitude of motion should not be too small.

6.3 Contributions and future work

This research contributes to the field of human-computer interaction by introducing effective ways of coding affect into motion. Our results may be used in a variety of applications, including notification interfaces, social computing and visualization. Using our findings, perceptual affects and impressions can be computationally manipulated in a display environment as variables of affective communications. We hope that this work will be applied to the development of interactive tools and techniques that provide a language of affective and expressive motion patterns for interaction and user experience designers.

Appendix A

Motion Database

A.1 Motion trajectory paths

Trajectory paths of all of the motions collected in this study are presented here. Table A.1 shows all of the algorithmically generated and hand-drawn trajectories along with their associated ID numbers. Table A.2 presents trajectories obtained from the Performer A who participated in the Pilot experiment with the associated expressions encoded by the performer. Trajectories obtained from all of the participants in the subsequent studies are presented in Table A.3 with expressions they encoded. Table A.4 shows motion trajectories used in Experiment 2. We selected three types of motion trajectories from our database described above.

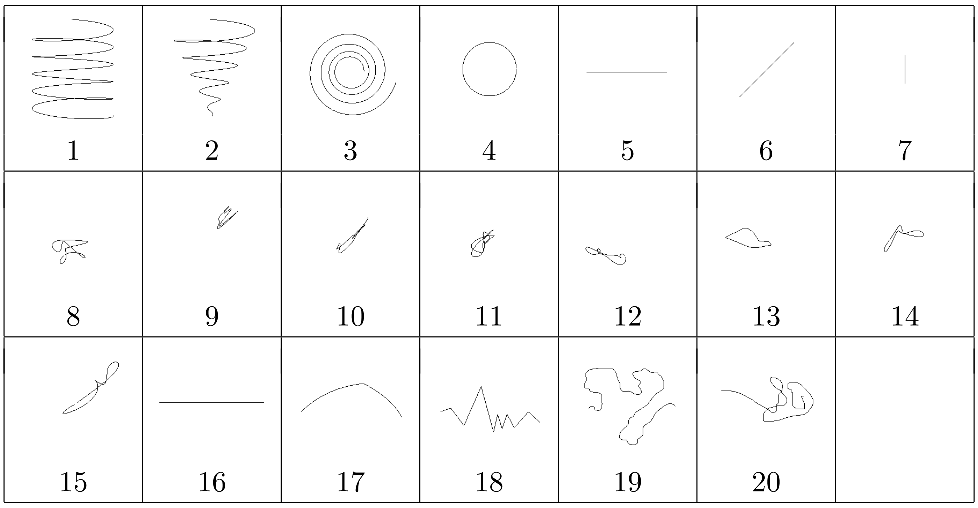


Table A.1: Algorithmically generated and hand-drawn trajectories with IDs.

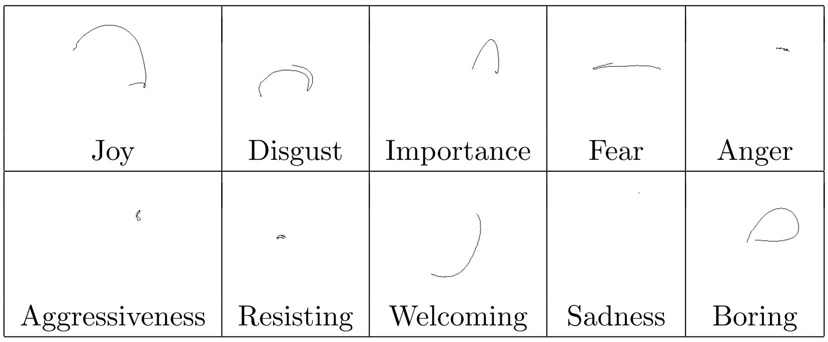


Table A.2: Motion captured trajectories used in the Pilot experiment.

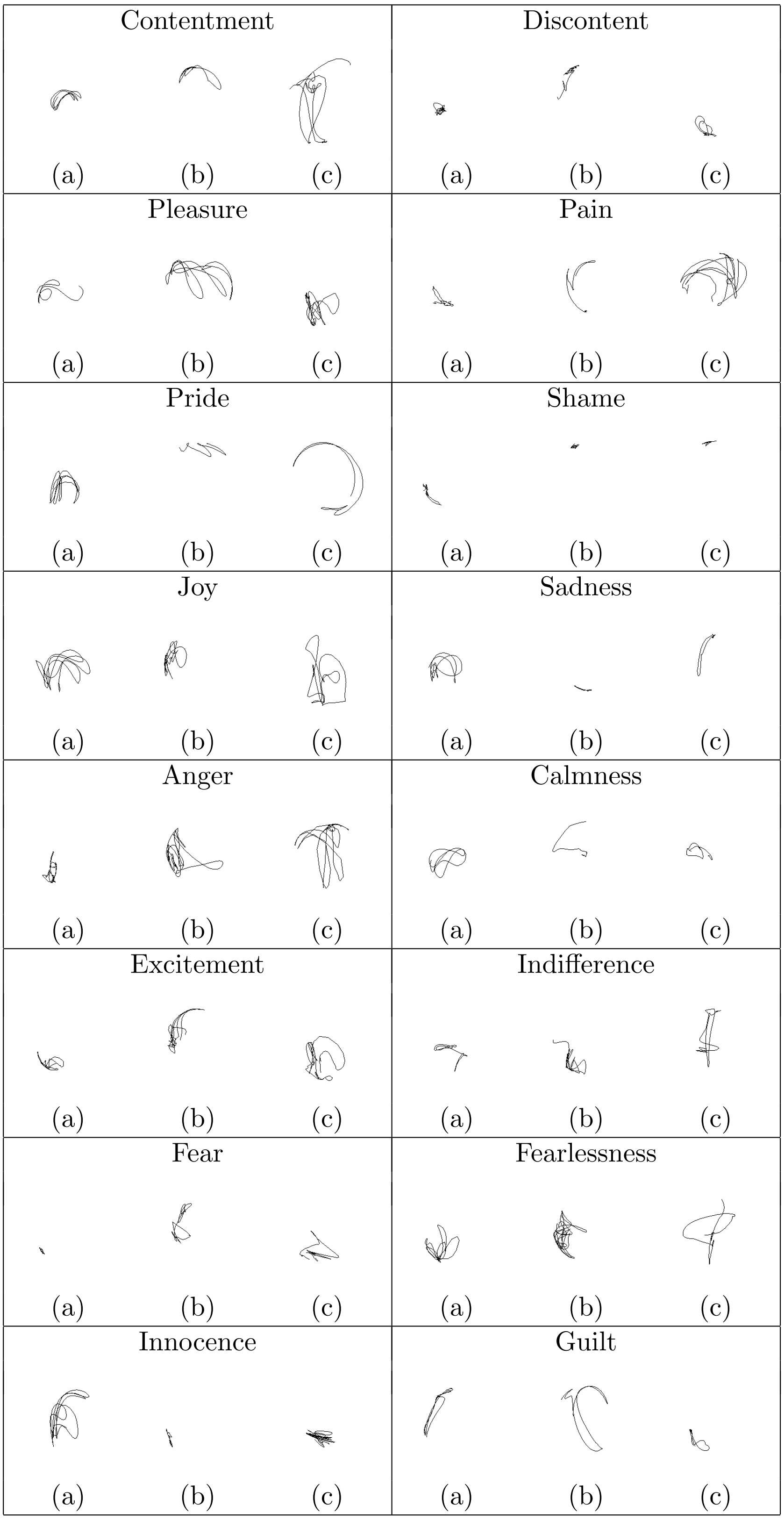


Table A.3: Motion captured trajectories of each expression obtained from (a) Performer 1, (b) Performer 2, and (c) Performer 3. Continue to the next table.

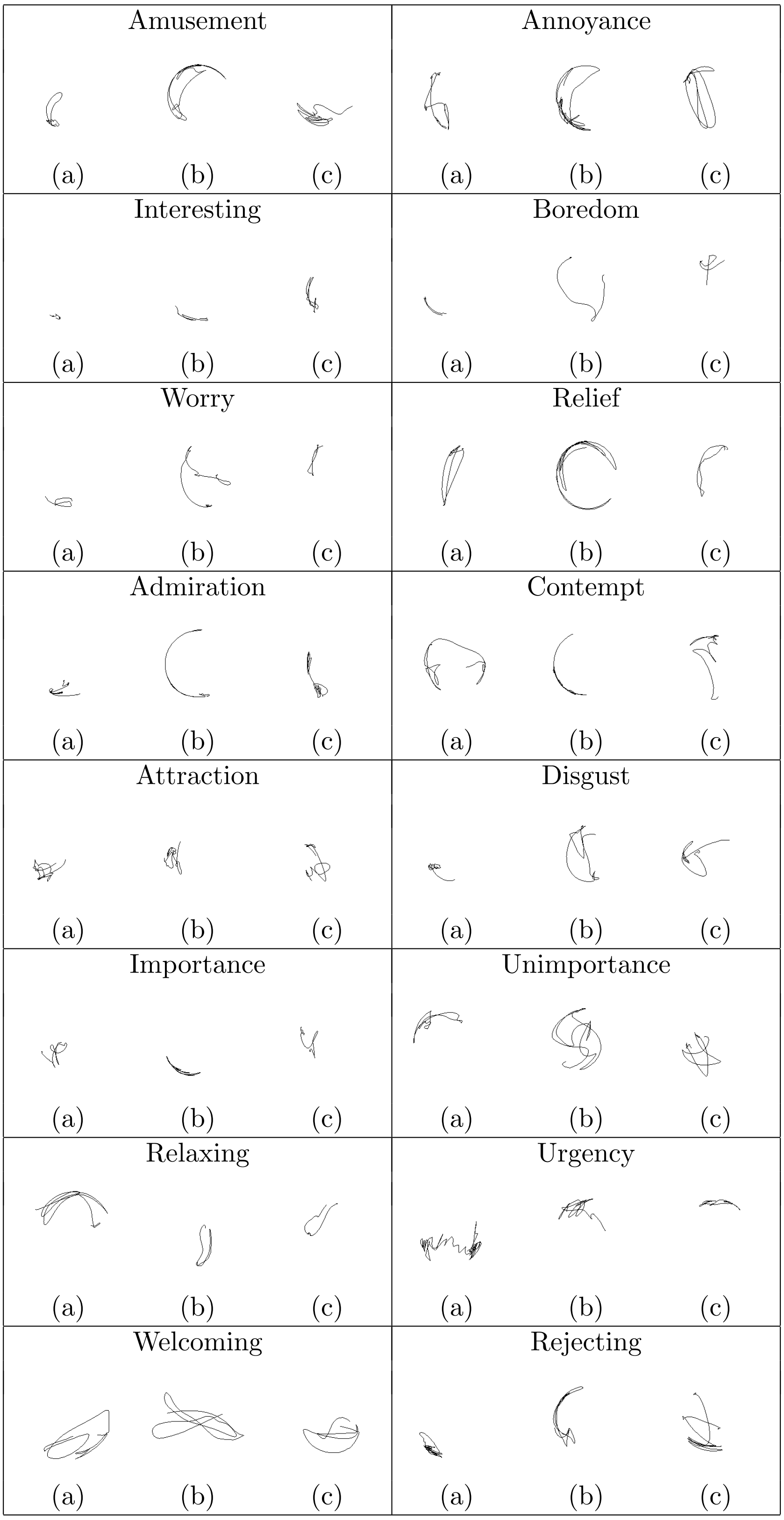


Table A.3: Motion captured trajectories of each expression obtained from (a) Performer 1, (b) Performer 2, and (c) Performer 3. Continued from the previous table.

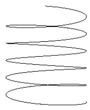
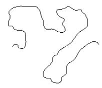
 *spiral*	 *linear-0*	 *linear-45*	 *linear-90*	 *tagiuri-H*	 *tagiuri-K*
 *tagiuri-E*	 *contentment*	 *discontent*	 *pleasure*	 *pride*	 *joy*
 *sadness*	 *anger*	 *calmness*	 *excitement*	 *indifference*	 *fear*
 *innocence*	 *guilt*	 *annoyance*	 *interesting*	 *boredom*	 *worry*
	 *relief*	 *contempt*	 *unimportance*	 *relaxed*	
	 *urgency*	 *welcoming*	 *rejecting*		

Table A.4: Motion trajectories selected for Experiment 2.

Appendix B

Experiment Displays

Screens captures from all of the experiments presented in this thesis are included here.

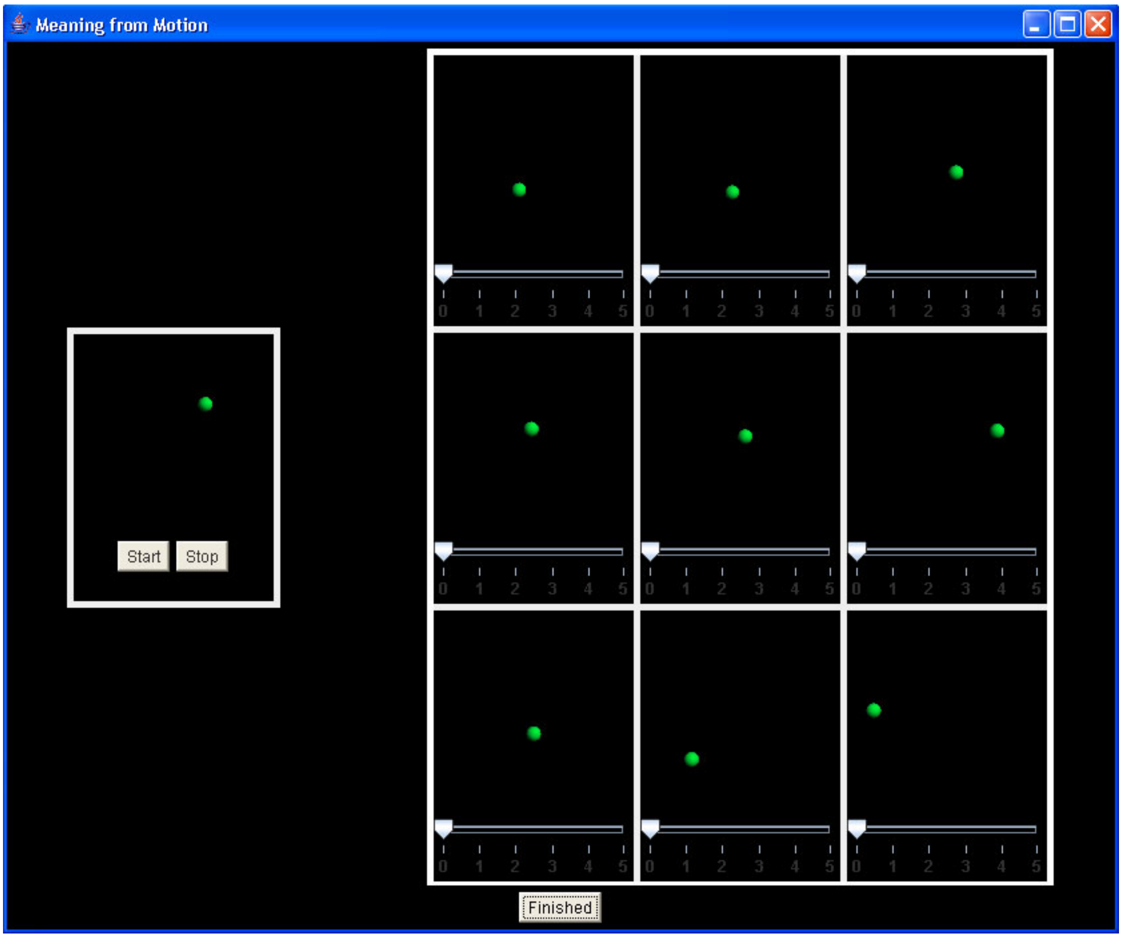


Figure B.1: Screen capture from the Pilot study

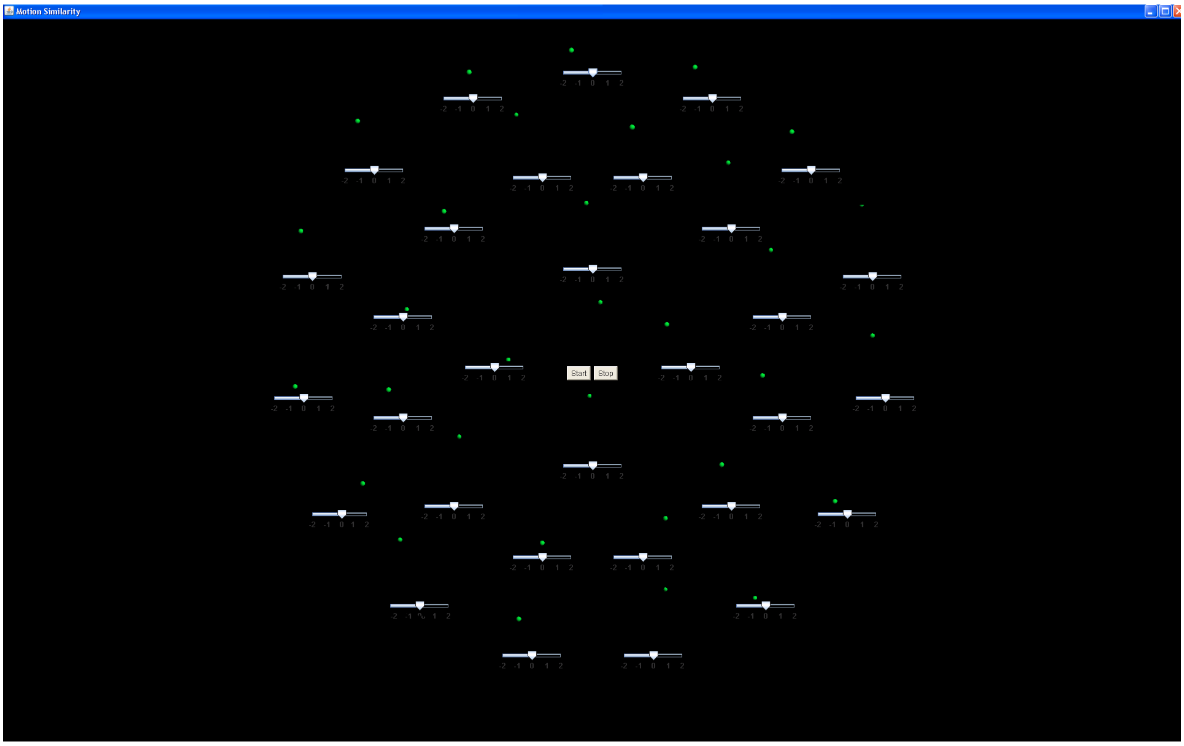


Figure B.2: Screen capture from Experiment 1A and 1B

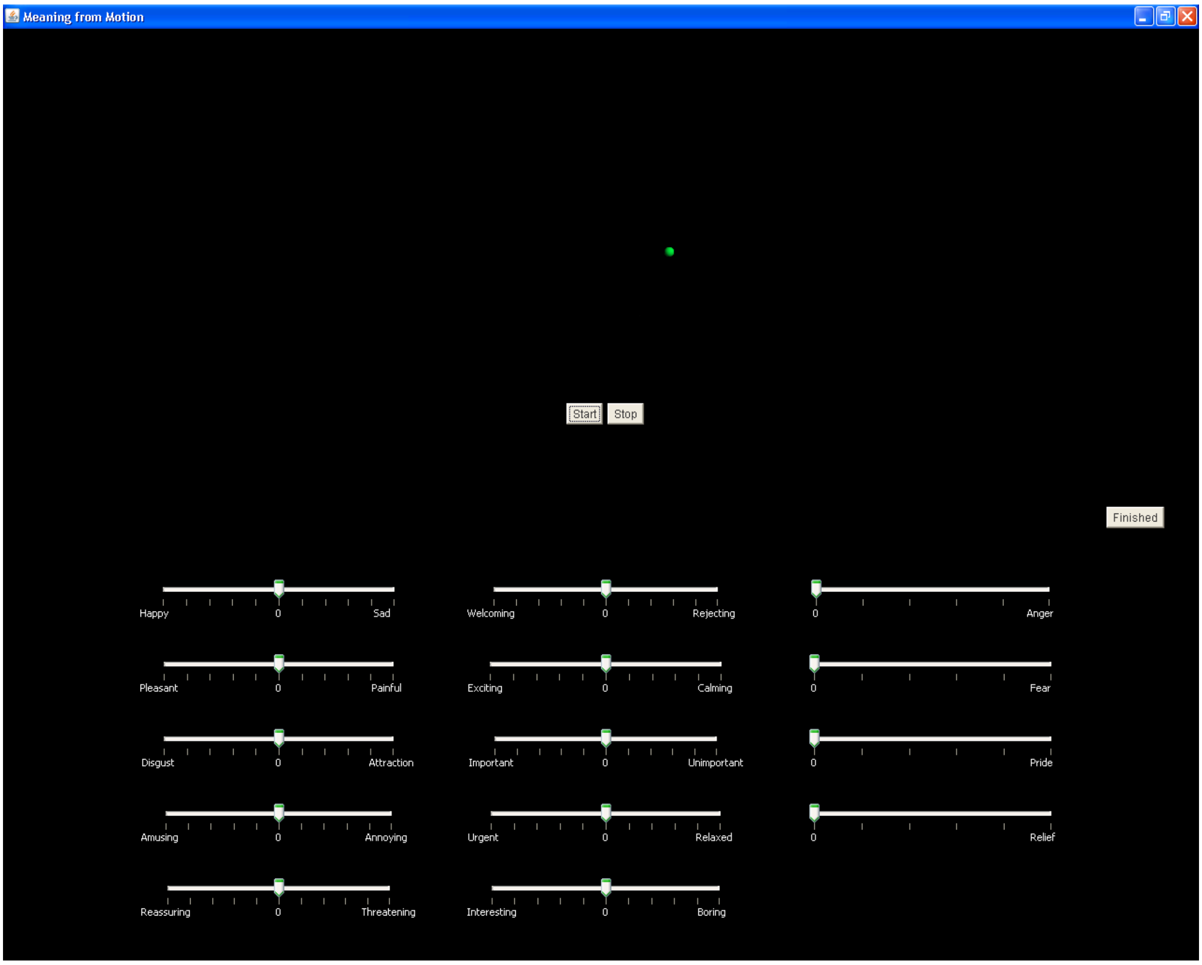


Figure B.3: Screen capture from Experiment 2

Appendix C

Algorithm For Statistically Balanced Randomization

The display for Experiment 1A and 1B showed a set of 32 motions that were structured with a source motion in the center, surrounded radially by 31 target motions. These target motions were distributed along three circular lines as shown in Figure C.1; Ring 1 consisted of 4 motions, Ring 2 consisted of 12 motions, and Ring 3 consisted of 15 motions.

There were two levels of order effects we wanted to avoid:

- Level 1: order in which stimulus motions were presented
- Level 2: order in which target motions were arranged around stimulus (different for each motion and participant)

Dr. Tom Loughin at School of Statistics at Simon Fraser University wrote the E-mails quoted in the subsequent sections as a response to our request to design statistically balanced randomizations. The first E-mail described the design for generating 32 screens per participant for 10 participants (10 sets of 32 screens) [29]. By evenly dividing among each set, the algorithm could generate 20 sets of 16 screens. However, we decided to use only 10 participants and 16 screens per participant. The second email was sent to us by Dr. Loughin later, describing the modified design to generate 10 sets of 16 screens [30].

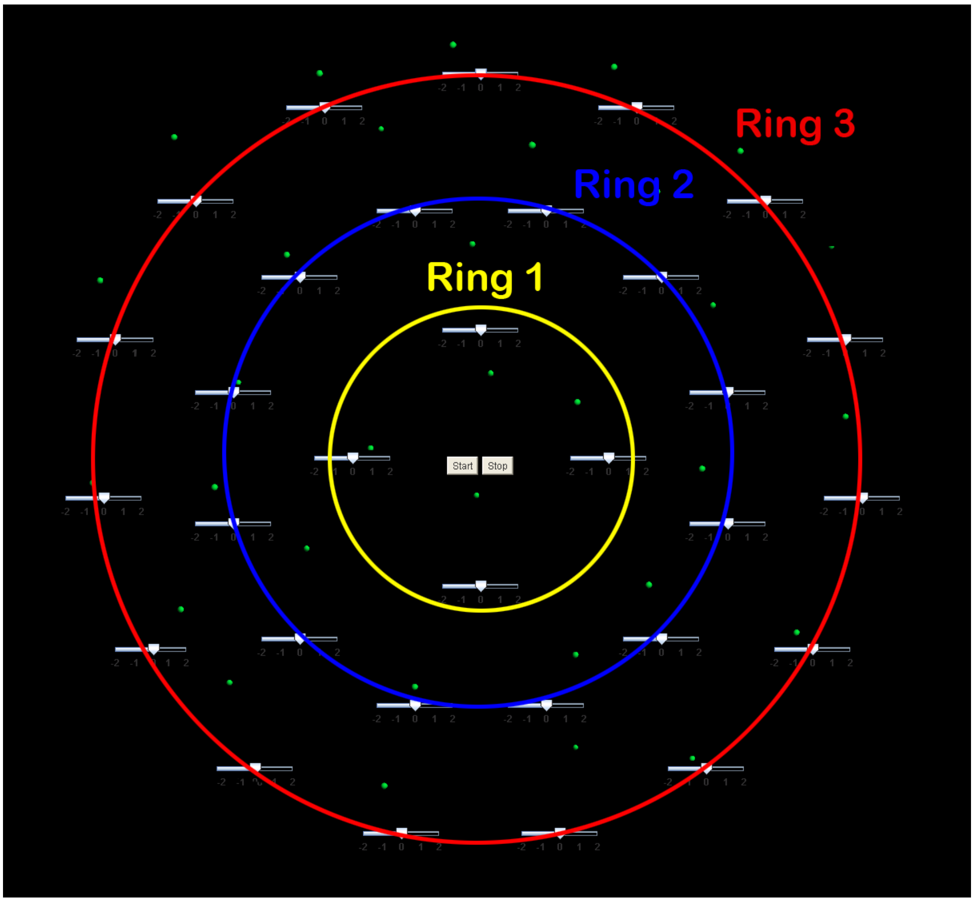


Figure C.1: 31 target motions distributed along three rings

C.1 Email regarding the random generation of 20 sets of 16 screens

The attached spreadsheet, Sheet 1[1] contains the randomization for 10 subjects corresponding to Target Motion #1. Across the top are the 10 subjects ... On the left are the 31 comparison motions, numbered 2-32. Inside the table is the ring into which a given comparison motion should fall, 1, 2, or 3. You have already indicated that you know how to perform randomizations, so I will try just explaining how to extend this out to a full experiment of 20 subjects and

[1]Referring Table C.1. The algorithm Dr. Loughin used to generate this table is beyond the scope of this thesis and therefore not included.

16 target motions each.

1. For Target=1, use the given table to construct your screens for Target 1. You can randomize the motions if you want to, but you don't have to.
2. For Target=2, start with the table from step 1. Randomly permute the rows, and then number the result in order with the comparison motions 1,3,4,...,32. Use the resulting table for your screens for Target 2.
3. For Target=3, repeat step 2, except for the obvious substitution of numbering the comparison motions to exclude #3. (It doesn't matter whether you start with the original table or with the result of the previous step; it will all get randomly reordered anyway).
4. Iterate this procedure until you have constructed screens for 10 subjects for all 32 Targets motions.

The table that we start off with is as balanced as it can be for comparing Target 1 to all other motions across the 10 subjects. The tables that you create afterwards are also as balanced as they can be for their respective Targets. The randomization of comparisons/rows ensures that a given subject doesn't always see the same motions in the same rings. However, each subject has 32 screens, and you want to do only 16 per subject. So for Subject 1, randomly select half of the target motions for Subject 1a and half for Subject 1b (two different subjects). Do a separate random split for the other 10 sets of 32 screens to create 20 sets of 16 screens.

Finally, for each subject, randomize the order in which the screens are shown.

C.2 Email regarding the random generation of 10 sets of 16 screens

Here is the new table: See the sheet labeled Start_Table_5 [2] ... The RING 1/2/3 columns are the counts of the number of times that motion gets assigned to Rings 1/2/3, respectively ...

[2] Referring to Table C.2

motion	sub1	sub2	sub3	sub4	sub5	sub6	sub7	sub8	sub9	sub10
2	3	3	3	3	2	1	2	2	3	2
3	2	3	3	2	3	3	1	3	2	2
4	3	3	3	3	1	2	3	2	2	2
5	3	3	2	3	2	1	3	3	2	2
6	2	3	3	3	3	2	1	2	1	2
...										...
28	2	3	1	3	2	3	2	3	3	2
29	3	3	2	2	3	3	3	2	2	1
30	3	3	1	1	2	3	2	3	2	3
31	3	2	2	2	3	3	3	2	3	1
32	3	2	2	2	1	3	3	3	3	2

Table C.1: Ring assignment table for 10 sets of 32 screens. This table shows only the first and last five rows.

There is one issue now with the smaller number of participants in each set: there are some comparator motions that do not ever get paired with a given target motion in Ring 1. For example, if you used the start table for Target=1, then Motion 2 never appears in Ring 1. It would be nice if we could guarantee that when Motion 2 is the target, Motion 1 would be forced to appear in Ring 1 at least once. That cannot be guaranteed for all pairs of motions by randomization. We would need to start with a randomization, look at the results, and then manipulate the motion-to-ring assignments a little bit in a structured way to achieve this additional level of balance. However, developing an algorithm to achieve this would take me a several more hours over the next few days[3] ...

[3]We did not ask Dr. Loughin to investigate further, since the solution was already feasible.

motion	sub1	sub2	sub3	sub4	sub5	ring1	ring2	ring3
2	2	3	3	3	2	0	2	3
3	2	3	3	2	3	0	2	3
4	3	3	3	2	2	0	2	3
5	3	3	2	3	2	0	2	3
6	2	3	3	1	3	1	1	3
...								...
28	2	3	1	3	2	1	2	2
29	3	3	2	2	3	0	2	3
30	3	3	1	2	2	1	2	2
31	3	2	2	1	3	1	2	2
32	3	2	2	3	1	1	2	2

Table C.2: Ring assignment table for 5 sets of 32 screens. This table shows only the first and last five rows.

Appendix D

Motion Attributes

Table D.1 shows the definitions used for characterizing each motion for each experiment described in this thesis. “Same” means that the definition in the previous study is used. “N/A” indicates that the attribute has been excluded from the list or not yet included in the list. For some attributes, their definitions are changed or improved through different studies.

Definition/Attribute	Pilot	Experiment 1A	Experiment 1B	Experiment 2
Speed	Length motion travels in one time frame	Same	Same	Same
Amplitude	Maximum distance between two points in the trajectory	Same	Same	Same
Acceleration	Number of times motion accelerates in one time frame	Same	Same	Same
Deceleration	Number of times motion decelerates in one time frame	Same	Same	Same
Frequency	Number of times motion repeats itself in one time frame	N/A	N/A	N/A
Direction	Diagonal, major axis (X or Y), north, south, east, west	N/A	Diagonal, major axis (X or Y), or random	Same
Curviness	Curvy, straight, or combined	N/A	N/A	N/A
Fluidity	N/A	Smooth, jerky, or combined	Same	Same
Shape	Circle, linear, arch, spiral, random, or a combined	Straight, angular, curvy, or combined	Same	Same

Table D.1: Motion attributes and their definitions used for each experiment. Continued to the next page

Path self-intersection		Number of self-intersections	N/A	Same	Same
Open/Closed path		Closed or open	N/A	N/A	N/A
Directional changes	Obtuse	Number of directional changes where the angle of two path segments is smaller than 135 degrees but greater than or equal to 90 degrees	N/A	Same	Same
	Sharp	Number of directional changes where the angle of two path segments is smaller than 90 degrees	N/A	Same	Same
Emotional contents		Emotional or algorithmic	Positive or negative Active or non-active Dominant or vulnerable	Same	Same
Position	Vertical	N/A	N/A	Top, center, or bottom	Same
	Horizontal	N/A	N/A	Left, center, or right	Same

Table D.1: Motion attributes and their definitions used for each experiment. Continued from the previous table

Appendix E

Additional Figures and Tables

Additional figures and tables mentioned in this thesis are provided here. Tables E.1 and E.2 show the eigenvalues of the correlation matrix used for estimating the number of factors for the BIG and SMALL motions, respectively. Tables E.3 and E.4 show the weights of each original rating for each factor, with the bottom row showing how much of the variance each factor accounted for. Figures E.1, E.2, E.3, E.4, E.5, and E.6 show the mean ratings on each motion for each expression associated with factors BIG-NEGATIVE, BIG-POSITIVE, BIG-CALM, SMALL-POSITIVE, SMALL-CALM, and SMALL-NEGATIVE, respectively. The ratings are sorted from high ratings to low ratings by an expression which has the strongest association with the factor. The shape of the plots indicates the shape of each motion, and the size of the plots indicates speed.

	Eigenvalue	Difference	Proportion	Cumulative
1	4.92	0.78	0.20	0.20
2	4.14	1.00	0.17	0.38
3	3.13	1.95	0.13	0.51
4	1.18	0.14	0.05	0.56
5	1.04	0.14	0.04	0.60
6	0.90	0.09	0.03	0.64
7	0.82	0.08	0.03	0.67
8	0.73	0.01	0.03	0.70
9	0.72	0.09	0.03	0.73
10	0.63	0.01	0.03	0.76
11	0.62	0.03	0.03	0.78
12	0.59	0.01	0.02	0.81
13	0.58	0.04	0.02	0.83
14	0.54	0.07	0.02	0.86
15	0.47	0.00	0.02	0.88
16	0.47	0.06	0.02	0.89
17	0.41	0.02	0.02	0.91
18	0.39	0.04	0.02	0.93
19	0.34	0.01	0.01	0.94
20	0.33	0.03	0.01	0.96
21	0.30	0.01	0.01	0.97
22	0.29	0.01	0.01	0.98
23	0.28	0.09	0.01	0.99
24	0.19		0.01	1.00

Table E.1: Eigenvalues of the correlation matrix (BIG)

	Eigenvalue	Difference	Proportion	Cumulative
1	4.63	1.27	0.19	0.19
2	3.35	1.34	0.14	0.33
3	2.02	0.71	0.08	0.42
4	1.31	0.09	0.05	0.47
5	1.21	0.19	0.05	0.52
6	1.02	0.07	0.04	0.56
7	0.96	0.03	0.04	0.60
8	0.93	0.05	0.04	0.64
9	0.88	0.06	0.04	0.68
10	0.82	0.06	0.03	0.71
11	0.75	0.04	0.03	0.74
12	0.72	0.08	0.03	0.77
13	0.64	0.01	0.03	0.80
14	0.63	0.07	0.03	0.82
15	0.57	0.02	0.02	0.85
16	0.54	0.04	0.02	0.87
17	0.50	0.05	0.02	0.89
18	0.45	0.03	0.02	0.91
19	0.42	0.03	0.02	0.93
20	0.39	0.02	0.02	0.95
21	0.37	0.03	0.02	0.96
22	0.35	0.05	0.01	0.98
23	0.30	0.04	0.01	0.99
24	0.25		0.01	1.00

Table E.2: Eigenvalues of the correlation matrix (SMALL)

	BIG-NEGATIVE	BIG-POSITIVE	BIG-CALM
painful	0.78	-0.08	0.01
threatening	0.77	0.00	-0.18
rejecting	0.75	-0.06	-0.01
angry	0.69	0.10	-0.16
urgent	0.66	0.16	-0.28
fearful	0.66	-0.09	0.15
disgusted	0.61	-0.16	0.21
annoying	0.59	-0.18	0.03
important	0.41	0.35	-0.23
sad	0.36	-0.13	0.59
proud	0.25	0.31	-0.02
exciting	0.24	0.77	-0.20
unimportant	0.17	-0.04	0.71
interesting	0.02	0.70	-0.08
boring	0.02	-0.18	0.69
attracted	0.01	0.60	-0.02
calming	-0.10	-0.09	0.75
amusing	-0.12	0.82	0.01
happy	-0.15	0.82	-0.06
relaxed	-0.15	0.10	0.68
reassuring	-0.16	0.37	0.46
pleasant	-0.19	0.73	0.17
welcoming	-0.21	0.69	0.18
relieved	-0.21	0.23	0.65
Proportion	21%	17%	13%

Table E.3: Weights of each original variable for each factor, sorted by the first factor (BIG).

	SMALL-POSITIVE	SMALL-CALM	SMALL-NEGATIVE
amusing	0.73	0.03	-0.15
welcoming	0.69	0.16	-0.17
pleasant	0.68	0.29	-0.24
happy	0.66	-0.00	-0.23
interesting	0.65	-0.16	-0.00
attracted	0.53	-0.05	-0.10
exciting	0.53	-0.35	0.17
important	0.46	-0.1	0.34
reassuring	0.44	0.64	-0.08
proud	0.43	0.02	-0.02
relieved	0.24	0.73	-0.12
relaxed	0.15	0.81	-0.18
urgent	0.14	-0.37	0.43
angry	0.05	-0.15	0.71
threatening	-0.01	-0.19	0.59
calming	-0.02	0.77	-0.18
rejecting	-0.05	-0.07	0.52
disgusted	-0.09	0.09	0.57
painful	-0.11	-0.03	0.69
fearful	-0.13	-0.15	0.39
sad	-0.16	0.28	0.26
unimportant	-0.21	0.46	-0.07
annoying	-0.23	0.02	0.49
boring	-0.28	0.44	0.08
Proportion	19%	13%	8%

Table E.4: Weights of each original variable for each factor, sorted by the first factor (SMALL).

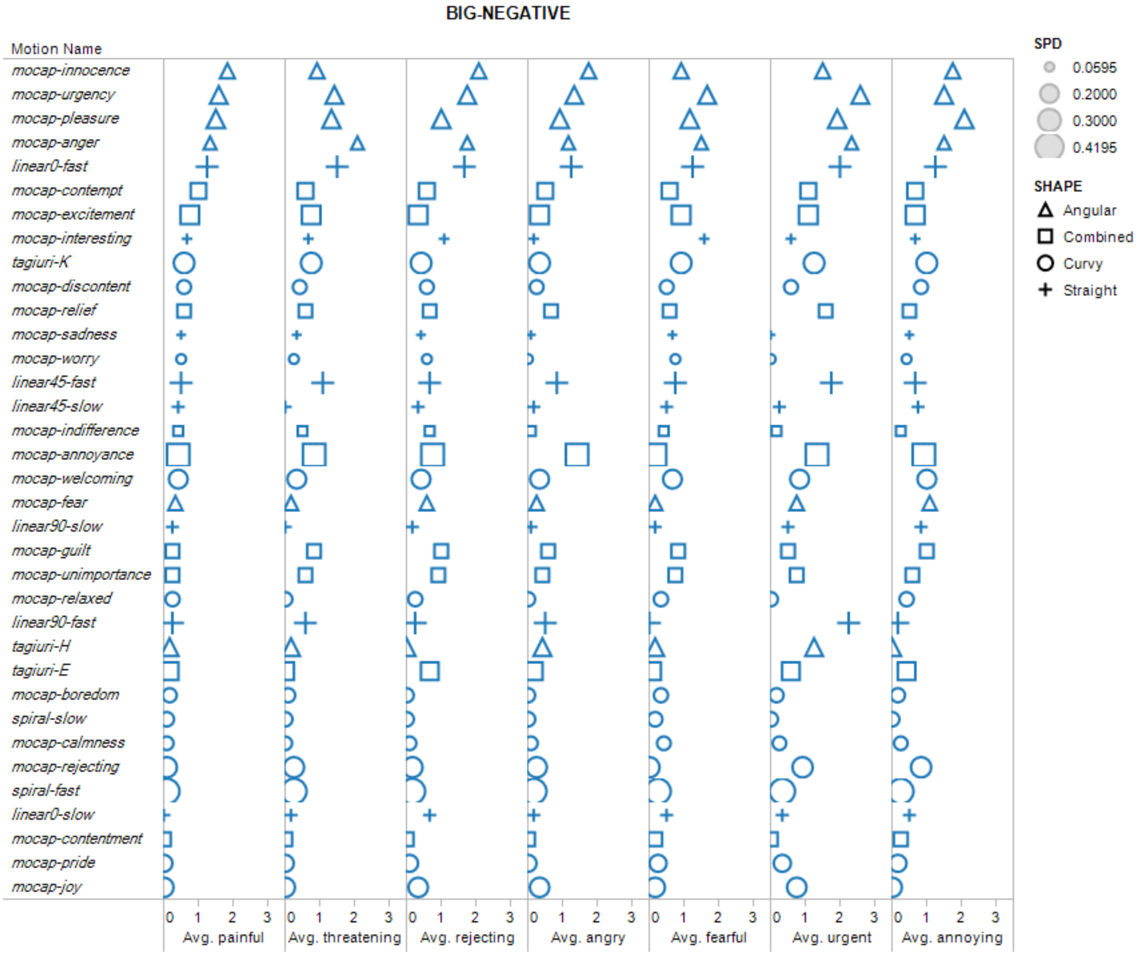


Figure E.1: Mean ratings for impressions that are correlated with the BIG-NEGATIVE factor.

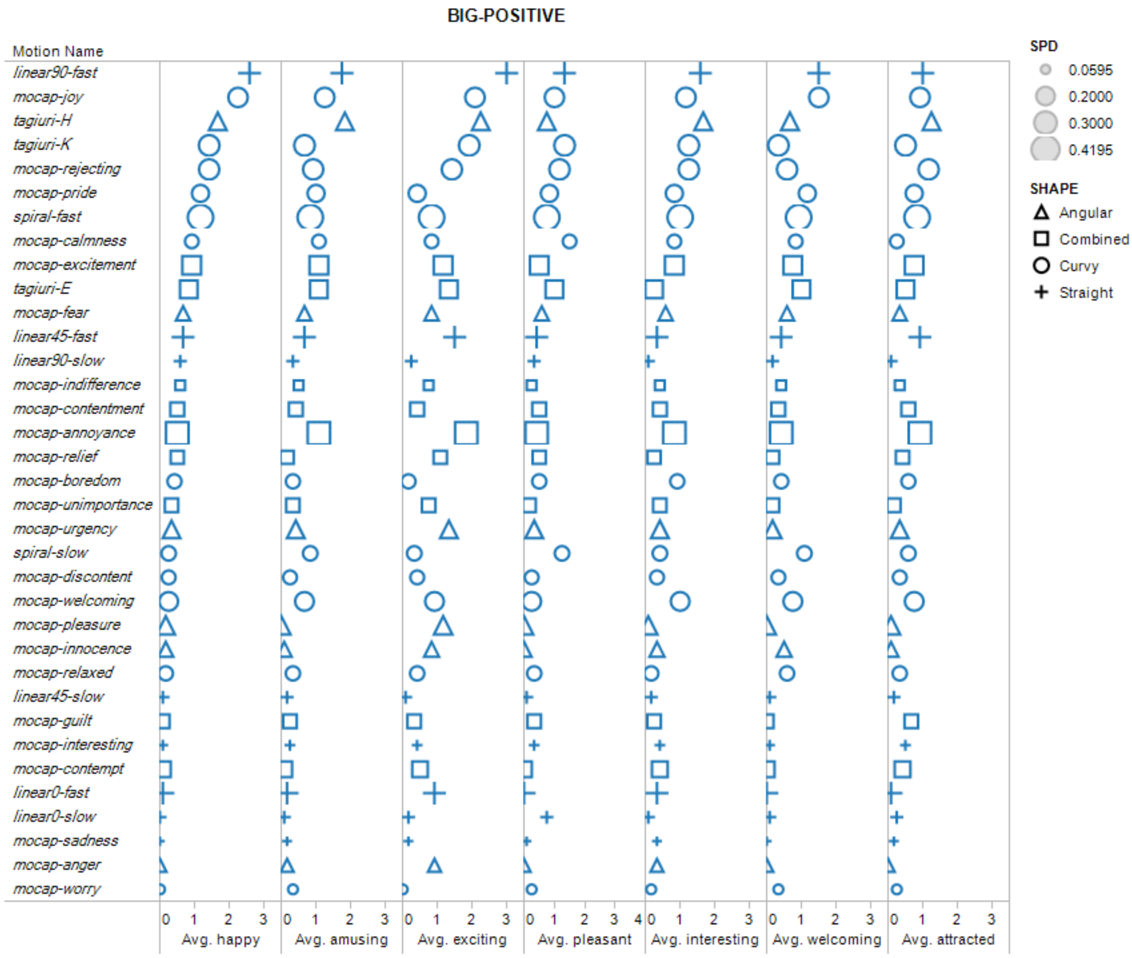


Figure E.2: Mean ratings for impressions that are correlated with the BIG-POSITIVE factor.

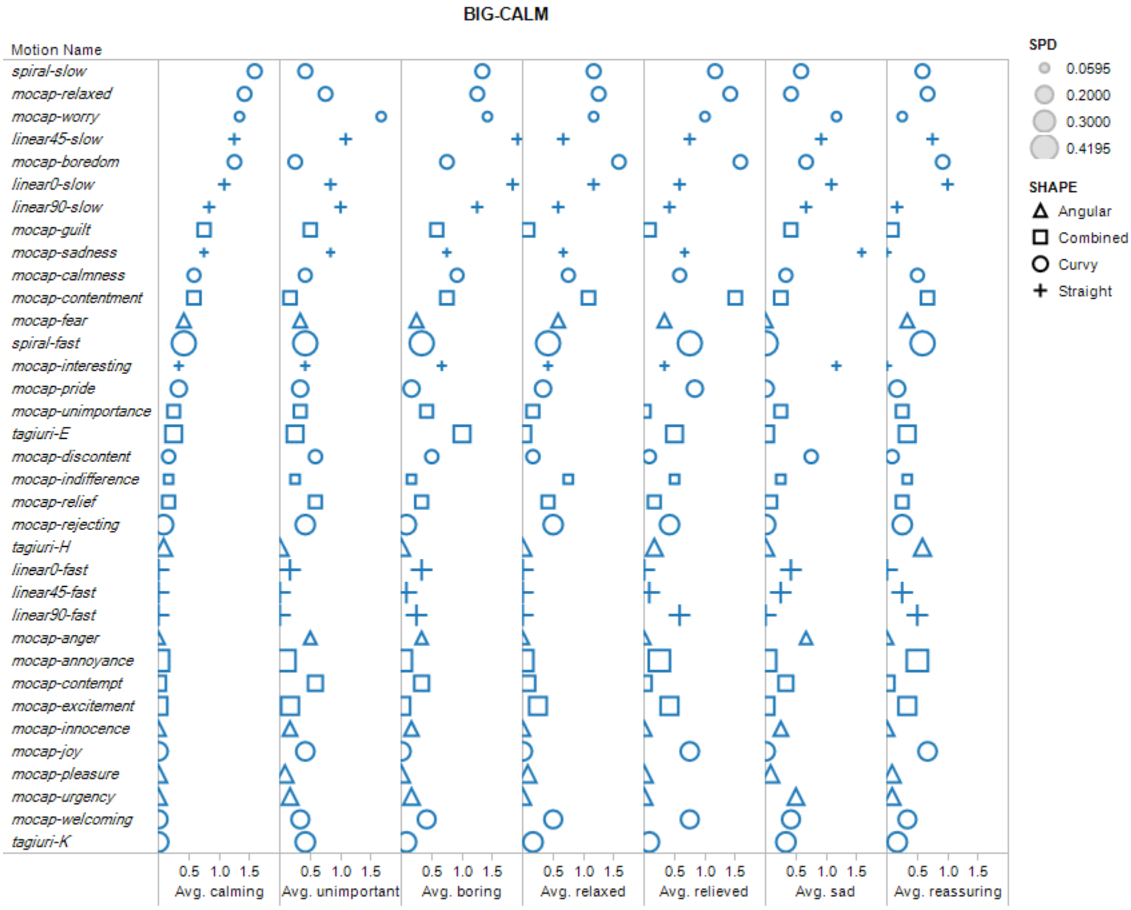


Figure E.3: Mean ratings for impressions that are correlated with the BIG-CALM factor.

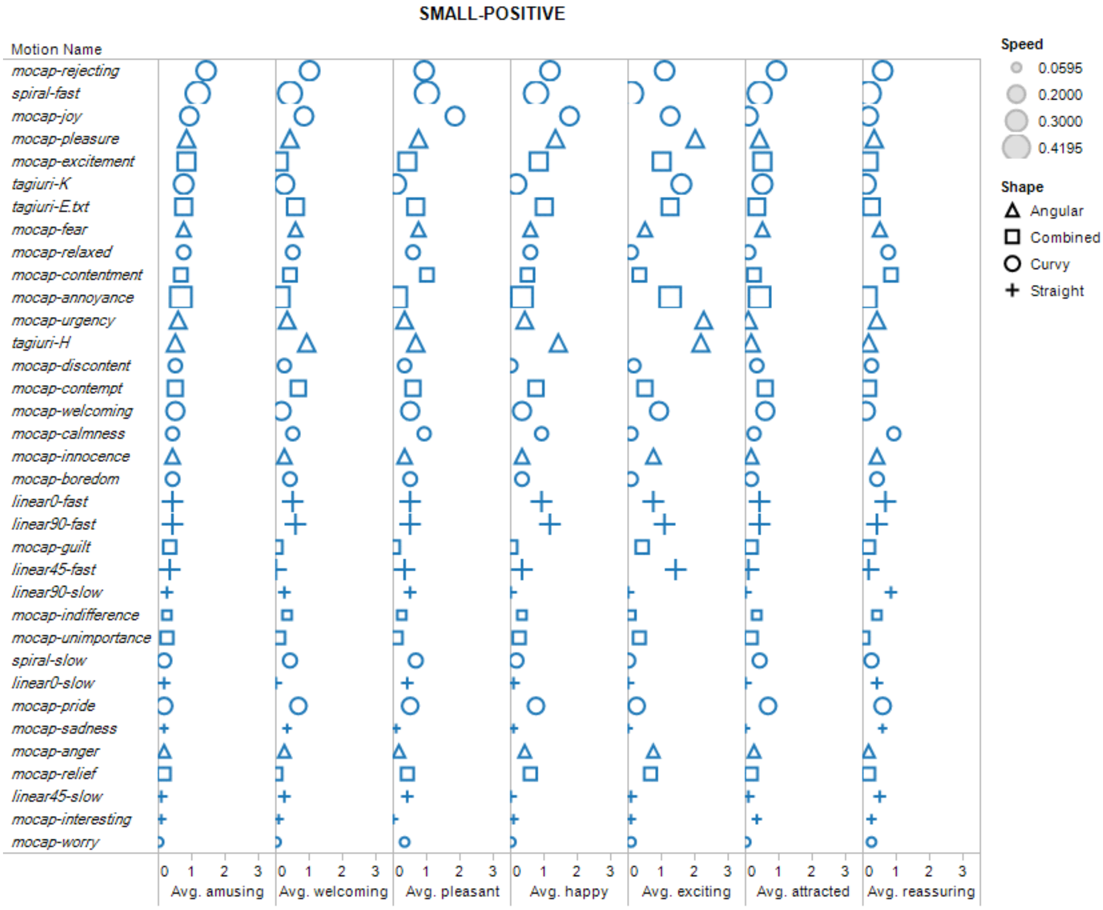


Figure E.4: Mean ratings for impressions that are correlated with the SMALL-POSITIVE factor.

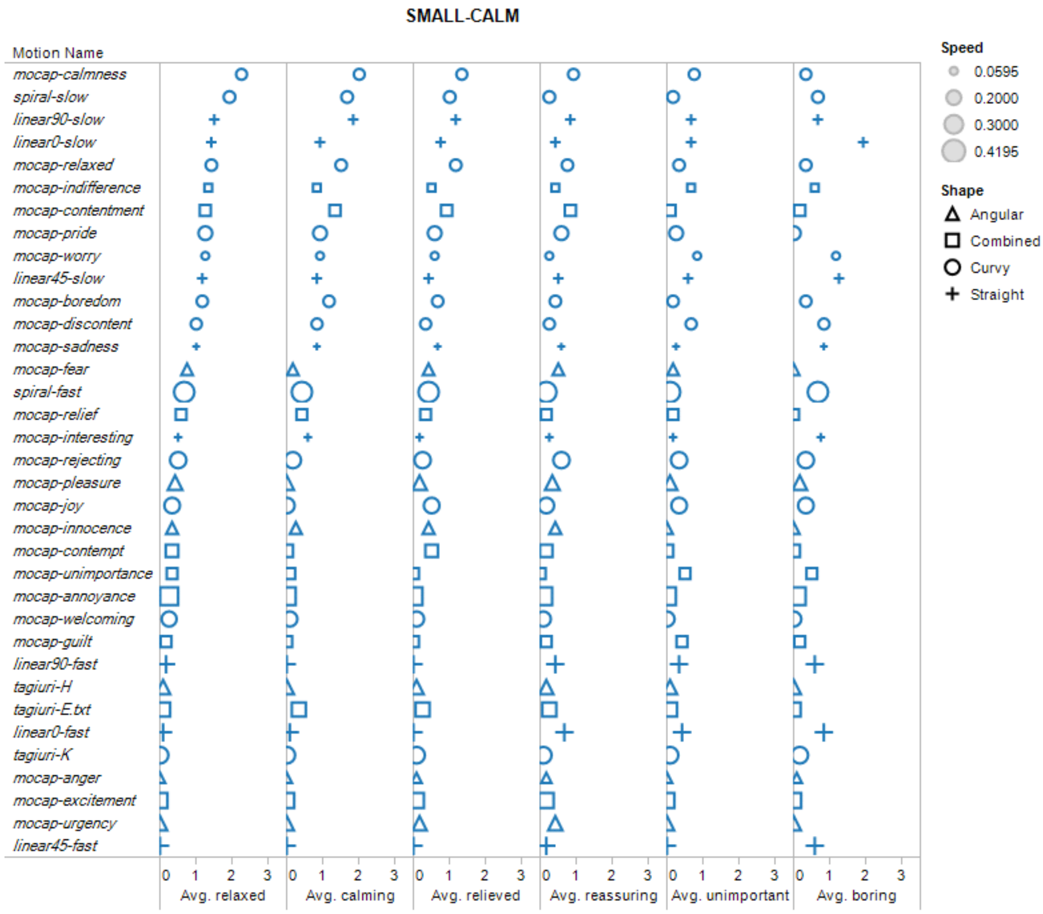


Figure E.5: Mean ratings for impressions that are correlated with the SMALL-CALM factor.

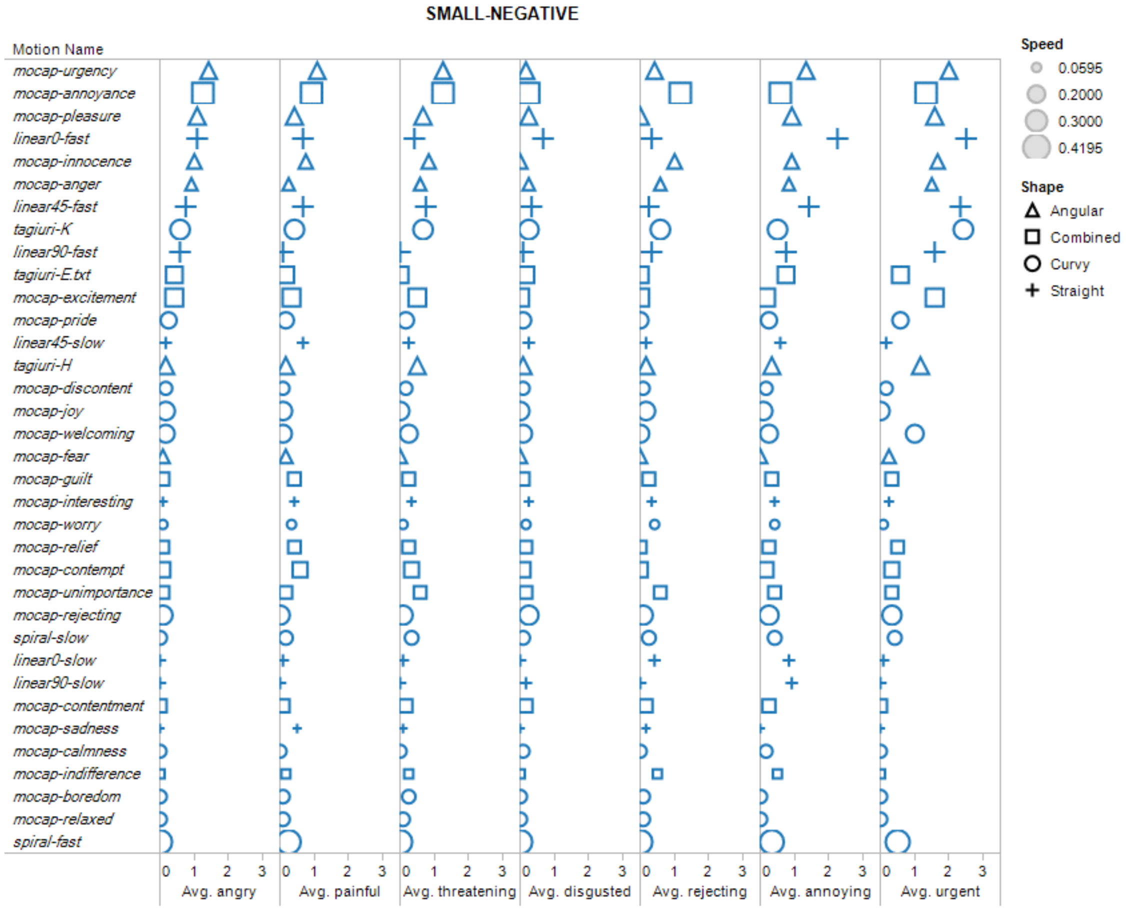


Figure E.6: Mean ratings for impressions that are correlated with the SMALL-NEGATIVE factor.

Appendix F

DVD Data

The DVD attached forms a part of this work. It consists of two different demonstrations: Motion Database and Flag Icon. Each demo contains a ReadMe.txt file which explains how to run the demo.

F.1 Motion Database Demo

Motion Database provides demonstration of all of the motions used in the experiments (trajectories are shown in Appendix A). The software is written in JOGL (3D Java), and the executable implementations of the demo for the Windows and Macintosh platforms are included on the DVD. They require JRE 1.6.0 (Java Runtime Environment) to be installed for proper execution.

Software

- Executable .jar files.
- JOGL libraries

Supporting data files

- Motion trajectory files which list 2 or 3 dimensional coordinates.
- Motion database file which list all of the motions and their sources.

F.2 Flag Icon Demo

Flag Icon provides demonstration of positive, negative, and calm motions generated based on our design guidelines provided in Chapter 6. Motion trajectories for these motions are shown in Table F.1. Motion shapes were chosen from our motion database, and then speed, amplitude, and/or position were changed based on the guidelines. We also generated the following three flags to show how the country is doing at the Olympic Games:

- Canada: happy/winning (positive)
- Japan: relatively happy/performing satisfactorily (positive but little slower)
- Pirates: sad/losing (calm but positioned lower to show negativeness)

The software was written in ActionScript 2.0 using Macromedia Flash and provided with an executable .swf file. Adobe Flash Player needs to be installed for proper execution.

		
Positive	Negative	Calm

Table F.1: Expressive motions generated based on our findings

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[1] K. Amaya, A. Bruderlin, and T. Calvert. Emotion from motion. *Graphics Interface 96*, pages 222–229, 1996.

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