EMOTION DEPICTION: EXPRESSIVE CHARACTER SEQUENCES USING PAINTERLY RENDERING

by

Hasti Seifi
Bachelor of Information Technology Engineering,
University of Tehran, 2008

THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

In the
School of Interactive Arts and Technology

SIMON FRASER UNIVERSITY
Fall 2010

APPROVAL

Name: **Hasti Seifi**

Degree: **Master of Science**

Title of Thesis: **Emotion Depiction: Expressive characters sequences using painterly rendering**

Examining Committee:

Chair:

Dr. Marek Hatala
Associate Professor
School of Interactive Arts & Technology

Steve DiPaola
Senior Supervisor
Associate Professor
School of Interactive Arts & Technology

Dr. Brian Fisher
Supervisor
Associate Professor
School of Interactive Arts & Technology

Dr. Magy Seif el-Nasr
External Examiner
Assistant Professor
School of Interactive Arts & Technology

Date Defended/Approved: December 03, 2010

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ABSTRACT

This thesis proposes a technique to enhance emotional expressiveness in games and animations. Past studies have shown that people associate specific colours with certain emotions. Furthermore, some studies demonstrated the effect of textural variations and brush properties on viewers' perception as well as their gaze pattern while looking at a portrait painting. Motivated by previous studies, we hypothesized that the appropriate use of colour palette and brush properties increases the emotions perceived in a facial character sequence. In order to examine this hypothesis, we programmed test sequence data and conducted a series of studies. In general, the results of the studies supported our hypothesis, which verifies the importance of visual style on viewers' perception while watching an animated sequence. This technique can provide the animator with a depiction tool to enhance the emotional content of a character sequence in games and animations.

Keywords: facial expressions; expressive games; Non-photo Realistic Rendering; colour-palette; painterly texture; focus of attention; game; animation; avatar; user study; user perception.

To my wonderful parents

and

all great people that try to build a better world

ACKNOWLEDGMENTS

My first and sincere appreciation goes to Steve DiPaola, my senior supervisor for all I have learned from him and for his continuous help and support in all stages of this thesis. I would also like to thank him for being an open person to ideas, and for encouraging and helping me to shape my interest and ideas.

I would like to express my deep gratitude and respect to James T. Enns whose advices and insight was invaluable to me. For all I learned from him, and for providing the Vision Lab for the experiments. His attitude to research inspired me to continue to a PhD program and want to be a member of the academic family.

In addition, I would like to thank Brian Fisher for accepting to be my supervisor in this project and for his interesting “Quantitative Methods” course, which helped me to address my research question. Also, thanks to Magy Seif El-Nasr for accepting to be the external examiner in my committee.

I would like to thank Terry Chu, an undergraduate student at the Department of Psychology at UBC, who was involved in this project from the start and was a great help in running the experiments at the UBC Vision Lab. Through running the experiments, he was highly responsible and cooperative with solving the problems about running the studies.

My greatest appreciation and friendship goes to my closest friend, Reza Shahidinejad, who was always a great support in all my struggles and frustrations in my new life and studies in this country. Cheers to Reza for being a great reliable person to whom I could always talk about my problems and excitements. Thanks him for questioning me about my ideas, helping me think rationally and even for hearing my problems.

I would like to thank my family, especially my mother and father for always believing in me, for their continuous love and their supports in my decisions. Without whom I could not have made it here.

Thanks to my supportive friend, Maryam Saberi, and others who made the lab a friendly environment for working.

In the end, I want to thank Steve DiPaola, Ali Arya, and Brendan Vance for providing me the software programs that I used for this research; in particular, Ali Arya for designing and developing iFace, and Brendan Vance for developing the Painterly system.

I was concerned that I might forget to mention someone or I might want to add to this acknowledgement later. Then, a good friend, Amin Shali, suggested a great idea, that I could put my acknowledgement online to be able to update it later. Thus, here is the link to the online acknowledgement for people who see this thesis later: www.hastiseifi.com/acknowledgment

STATEMENT OF CO-AUTHORSHIP

I formed the initial hypothesis of this work during IAT812 course based on Steve DiPaola's idea on using the painterly rendering technique for facial animation sequences. During the course of refining and conducting the experiments, I benefited from invaluable advice and help from Steve DiPaola, James T Enns (head of the UBC Vision Lab), and Terry Chu (his undergraduate researcher). Thus, these studies are the result of our collaboration as a group. Following is a brief explanation of the division of roles for conducting the studies:

The "iFace" and "Painterly" programs (developed by Steve DiPaola and past iVizlab team members) were the primary programs for generating the experiment movies. To leverage iFace features for making animation sequences, I developed a keyframe editor extension for iFace. Furthermore, for making the painted movies, I wrote a set of scripts to define the appropriate painterly settings and to apply those settings to a sequence of frames. In addition, at the beginning of this project, I wrote the experimental apparatus to display the movies and capture users' responses in the studies. Before each study, we usually had a group meeting to discuss the results of the previous study and plan the next steps. During the discussion, DiPaola and I provided information on the non-photorealistic rendering and previous affective studies. Enns usually helped in refining the experimental design. Then, after each group meeting, I prepared the generated movies and applied the required modification to the apparatus for the next study. I was also conducting the required pilot studies at SFU to help with planning the next steps. All the main studies were conducted at the UBC Vision Lab. Chu, an undergraduate student at the department of psychology of UBC, was scheduling and running the user studies. After receiving complete data for each study, I analysed the raw data and sent my findings to the group together with the raw data. Then, others in the group especially Enns would also send their additional analysis to the group. Among the tables and figures provided in this document, Table 4, Figure 25, Figure 26, and Figure 27 are directly from Enns' analysis, all other tables/charts are from my analysis using SPSS based on either my initial analysis of the data or Enns' additional analysis. While there was a strong collaboration component and this work was informed by and part of the ongoing work by the supervising faculty, I was solely responsible for addressing the specific question of this research.

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1: INTRODUCTION[1]

1.1 Overview

Facial expression is a non-separable part of an animated/virtual character. Many previous studies have demonstrated the importance of expressive facial movements on conveying emotions effectively, which enhances character believability. Although the importance of expressive facial movements is confirmed by past researchers (Ochs, Niewiadomski, Pelachaud, & Sadek, 2005; Pelachaud & Bilvi, 2003; Rosis, Pelachaud, Poggi, Carofiglio, & Carolis, 2003), a concrete computer graphics approach for effectively generating a full range of all expressions has not yet been proposed. Generally, animated sequences still need manual character tunings by animators to achieve a satisfying level of expressiveness. As a logical consequence, game characters and other automatically generated animation sequences do not exhibit comparable levels of facial expressiveness.

We believe that the expressiveness of emotional character sequences can be enhanced by merely changing the visual style of those sequences. One such visual style, and the suggested style of this thesis, is painterly rendering which simulates the work of illustrators and portrait artists and is commonly reported as an expressive style (Hays & Essa, 2004; Hertzmann, 2001, 2010; Lansdown &

[1] All the movies used in the user studies can be found at http://dipaola.org/lab/

Schofield, 1995). Thus, we are interested in exploring the effect of the painterly rendering style, colour palette in particular and to a less extent brush properties, on the users' perception of a facial character sequence. We form the research question as follows: Do colour palette and texture of a painterly rendered facial character sequence affect the perceived type and intensity of the expressed emotion(s) in that sequence? In this regard, colour palette was the primary focus of our studies and refers to the range of colours used for painting an animation frame e.g. a warm colour palette is composed of the red-orange analogous colours, and a cool colour palette mainly uses different shades of blue. The current work examines a number of colour palettes which we designed and refined based on art theories, and later based on research studies in the colour literature. Texture, which is the textural paint quality and style, is the result of brush characteristics such as its size, path and curvature. In this thesis, our main focus is on the effect of colour, but we examined texture as a secondary influencing factor and considered two aspects of texture: 1) addition of a sharper "center of interest" area where tighter stroking is used, 2) two different texture styles (i.e. brush stroke styles) referred to as jaggy and blurry. Chapter 3 includes a complete description of the colours and texture styles used in our studies.

Based on previous colour and texture studies (DiPaola, Riebe, & Enns, 2010; da Pos & Green-Armytage, 2007; Shugrina, Betke, & Collomosse, 2006), our general hypothesis is that *painterly depiction of a basic emotion with the congruent colour and texture properties in a facial character sequence will* *increase the perceived intensity for that emotion while rendering the same character sequence with the incongruent parameters for that emotion will reduce the perceived intensity of that emotion in the character sequence.*

In order to investigate our hypothesis, we conducted a series of user studies using our prepared computer generated, painterly rendered, facial animation sequences (or stills). The participants watched a number of short character sequences in which a 3D face animates from a neutral position to one of the facial expressions chosen, and after remaining on the full expression for about one second, it returns back to the neutral position. After each movie, the participants chose the intensity perceived for the emotional expression in the sequence on a slider with values from 0 to 6. Thus, the dependent variables of our studies are the perceived intensities for the six basic emotions and are measured based on the users' selections of one or multiple emotion sliders after watching a video.

In total, three pilot studies and three experiments were conducted to capture the hypothesized effect of using different palettes and brush styles on a character animation sequence. Table 1 provides a chronological overview of the user studies and their objectives.

Table 1- Summary of the user studies in a chronological order

User study	Purpose
First pilot study	Examine the sensitivity of the subjects to the three energy (intensity) levels and examine the appropriateness of the measuring scale used
Second pilot study	Capture possible differences perceived by the participants between natural CG movies and painterly rendered movies in original colour palette
First main study	Investigate the effect of warm and cool colour palettes on users' perception of an emotion in a facial character sequence
Second main study	Investigate the same effect as the previous study with a factor of "center of interest" area applied to the eye area
Third pilot study	Examine the effect of the redesigned colour palettes, now based on colour literature, on the still images of the four facial expressions chosen
Final study	Investigate the effect of the redesigned colour palettes on dynamic sequences of the four facial expressions

The two primary pilot studies helped in the design of the following studies. The first two main studies while suggested some colour trends for specific emotions, could not fully capture the effect of the chosen palettes, perhaps because separating the colour space into the warm and cool groupings does not result in the primary emotional elements required for a controlled study. Thus, we redesigned our colour palettes for the animated character sequences based on the research findings in the colour literature. The third pilot study verified the appropriateness of the new palettes on the facial still images, while in the final main study we applied a slightly modified version of these palettes to the animated sequences. The results of the final main study confirmed our hypothesis for the anger and joy expressions in the animated character sequences. In the case of the fear expression, the distinct pattern of ratings suggests the effect of colour palette. However, the applied congruent palette in the last study was not suitable for boosting the intensity of this expression. The results of the surprise ratings did not indicate any noticeable effect of colour palette.

Overall, the results of these studies support our hypothesis about the impact of colour on the users' perception of emotions in animated character sequences. A more focused study is required to explore the impact of brush stroke. Nevertheless, the application of various texture styles in the works of artists suggests such an impact.

Finally, one can define knowledge-based painterly rendering as an informed painterly rendering technique, which utilizes the knowledge about the scene and its emotional content together with the knowledge about the painterly techniques and their affective value, in order to make more expressive animated sequences. This technique can provide the animator with a depiction tool to boost/flavour the emotional content of the character scene and can be used along with other methods such as dramatic lighting and music techniques to achieve more appealing animated sequences (de Melo & Paiva, 2007). Thus, it has benefits to the animation, film and game industries. While in this thesis, we focus on the affective value of colour palettes and some brush properties for facial character sequences, other studies on other types of animated sequences can provide the required information for applying this technique on more general sequences such as sequences with whole body animation, landscape, etc.

1.2 Background and Motivation

To achieve high levels of expressiveness, today's animations not only rely on the animators' skills but also on other elements such as lighting, scene composition etc. The latter not only enhances the emotional content of the scene but also draws attention to the specific regions designed for conveying the message. Similarly, recent studies in human vision demonstrated that painting techniques could effectively guide a human's gaze through a portrait painting. Evidence has shown that painters as early as Rembrandt intuitively exploited these techniques to affect viewers' perception of the sitter and to tell a specific narrative (DiPaola et al., 2010).

Other studies have shown that people associate specific colours with certain feelings. For example, bright colours are joyful; blue is cold, tender, and sad; while red is happy, restless, and vigorous (Shugrina et al., 2006). Other recent studies suggested that users choose brighter, and more saturated colours for joy compared to colours for sadness (de Melo & Gratch, 2009). da Pos and Green-Armytage (2007) have investigated the relationship between colours and facial expressions and found overall consensus among European artists in pairing colours with facial expressions. Moreover, some previous studies demonstrated that there are links between rendering style and ones perception as well as feelings about the rendered object (Duke, Barnard, Halper, & Mellin, 2003; Halper, Mellin, Herrmann, Linneweber, & Strothotte, 2003; Hevner, 1935; Pelachaud & Bilvi, 2003; Shugrina et al., 2006; Whissell, 1989a). The rendering style may be a photorealistic rendering or different types of non-photorealistic renderings such as painterly, pen-and-ink illustrations, technical illustration, and cartoon. Even within one style such as the painterly rendering, different settings such as brush stroke shape and size, and colour palette can evoke different perceptions and/or emotional responses (Colton, Valstar, & Pantic, 2008; Halper et al., 2003; Shugrina et al., 2006). The studies conducted by DiPaola et al.(2010), and Santella & DeCarlo (2002) suggest that the pattern of eye movements based on texture characteristics can give an explanation for such results; thus confirming the usefulness of a psychophysical approach to Non-Photorealistic Rendering (NPR) studies.

Our work is motivated by these previous studies (DiPaola et al., 2010; da Pos & Green-Armytage, 2007; Shugrina et al., 2006), and is an effort to explore the effect of colour palettes and brush stroke on users' perception of emotions in animated character sequences. We hypothesize that the appropriate use of colour and painting style leads to conveying the emotions to the viewer more effectively and provides a more satisfactory emotional experience for the viewer/user.

1.3 Thesis Outline

In the following sections we present the related literature, the details of the experimental design and the user studies conducted, followed by a chapter on discussion, implications for future work, and applications of the work.

Chapter 2 states previous work on related areas. We divided the chapter into three main sections; the first section describes the most well-known psychological work on facial expressions by Paul Ekman and includes the description of six basic emotions and the facial landmarks of each. The second section is dedicated to research on expressive facial movements in three parts: 1) different approaches to computational facial expressions, 2) emotional spaces and finally, 3) expressive facial movements using emotional spaces. In the last section of this chapter, we will cover related research in non-photorealistic rendering in three parts: 1) painterly images and videos, 2) painterly work in an interactive context, and then 3) affective studies in colours and NPR.

Chapter 3 outlines the hypothesis for each study, the experimental designs to investigate the hypothesis including the independent and dependent variables as well as the experiment materials and conditions. Then, we define the parametric approach and its benefits for both face research and painterly rendering. Finally, we describe the parameters and components of two parametric systems, iFace and Painterly, that we programmed, scripted and used to prepare our generated painterly rendering animated sequences for the studies.

Chapter 4 is the detailed description of the experiments, results and the analysis of results. We will provide an overview of the common aspects of all experiments such as the head model and movies, the apparatus, and the experiment procedure used. Then, we move to the two pilot studies followed by the three main studies, specifying the settings for each study and its differences with previous studies under the study title. In addition, results of each study together with the analysis and discussion of the results are provided at the end of each study section.

In Chapter 5, we discuss the limitations and final discussions about the studies, followed by the implications for future work, and then the anticipated applications of the proposed technique.

2: RELATED WORK

The domain of this thesis spans over the intersection of 1) computer facial animation and 2) affect studies in colour and 3) non-photorealistic rendering. In other words, this thesis investigates the promise of painterly rendering as an expressive visual style to enhance the affective content of facial animations. Thus, previous related work falls in three areas: 1) Ekman's six basic expressions, 2) methods for expressive facial movements, and 3) affective studies in non-photorealistic rendering.

2.1 Ekman's Six Basic Expressions

Foundational research on facial expressions has mostly been conducted by psychologists, most notably Paul Ekman. Ekman has accomplished extensive studies in various cultures and has found strong evidence on the universality of the six basic expressions: joy, sadness, fear, anger, disgust and surprise. According to his work, facial expressions could be considered as families, consisting of a set of core configurational properties as well as variations. While these core properties distinguish each family of expressions from the others, the variations are caused by a number of factors such as the intensity of emotion, whether the emotion is controlled or not, the event that provoked it, and whether it is simulated or spontaneous (Ekman and Oster 1979). For this thesis, we are concerned with users' perception of the Ekman's six universal emotions and their combinations. Thus, in the following subsections, we will give a brief description of core facial landmarks associated with each of the six basic expressions (Figure 1). In general, for most of the expressions, the eye/eyebrow area and especially the mouth area plays a major role in recognizing the expression. The following sections on characteristics of each basic facial expression are based on Ekman's studies (Ekman & Friesen, 2003). Figure 1 displays a sample facial configuration for each of the six basic emotions.

Figure 1-Six basic facial expressions from (Ekman & Friesen, 2003)

2.1.1 Surprise

Surprise (Figure 1-a) is the briefest emotion with the shortest onset and duration. Surprise varies from the mild to extreme cases. The term *startle* refers to the most extreme surprise reaction, which is also closely related to fear.

Characteristics – In the surprise expression, the eyebrows move upward in a curved shape, the eyes widen and the jaw drops open. Although the intensity of surprise is directly related to how much the eyebrows go up and the eyes widen, but the major clue to the intensity of the surprise is in the mouth area. Signs of surprise in a person's face are:

- Raised eyebrows, so that they are curved and high
- Stretched skin in areas below the brow
- Horizontal wrinkles that go across the forehead
- Widened eyelids; with raised upper lid; the white of the eye-the sclera-appears above and below the iris
- A dropped jaw with the lips and teeth parted, and no tension or stretching of the mouth

2.1.2 Fear

Fear (Figure 1-b) differs from surprise in three important characteristics. First, surprise is not necessarily pleasant or unpleasant, but even mild fear is unpleasant. Second, surprise happens because of an unknown event but you can be afraid of something familiar as well as the unknown. Third, the durations of surprise and fear are different; Surprise is the briefest emotion, but the duration of fear could vary depending on its cause. Except for the duration, the two other differences between surprise and fear do not cause any visual differences between the two emotions and it is common to misrecognize these two expressions (see Figure 1-a, b)(Duke et al., 2003; Ekman & Friesen, 2003).

Facial signs of fear are as follows:

- Raised and drawn together eyebrows
- The wrinkles appear in the center of the forehead, not across the entire forehead.
- Raised upper eyelids, which expose sclera; the lower eyelids are tensed and drawn up.
- The mouth is open with the lips either tensed slightly and drawn back or stretched and drawn back.

2.1.3 Disgust

Disgust (Figure 1-c) is a feeling of aversion and varies in intensity from mild dislike to "nausea-vomiting" disgust. The major clues to disgust are in the mouth and nose and to a lesser extent in the lower eyelids and eyebrows. The upper lip is raised, while the lower lip may be raised or lowered, the lower eyelids move a bit upward, the eyebrows are lowered, and the nose is wrinkled. In mild disgust less nose-wrinkling occurs, and the upper lip moves less. In extreme disgust the tongue can be seen in the mouth and in some cases the tongue actually protrudes from the mouth. In brief, the facial landmarks associated with disgust are:

- A raised upper lip
- A raised lower lip that pushed up to the upper lip, or is lowered and slightly protruding.
- A wrinkled nose
- Raised cheeks
- Pushed up lower lids with some lines showing below them
- lowered brows, which also lower the upper lids

2.1.4 Anger

Anger (Figure 1-d) is an active emotion. The causes for anger, the reactions in that situation, and the time it takes to get angry, vary considerably among people. In addition, anger varies in intensity, from slight irritation or annoyance to rage or fury. It also can build gradually from the less intense to the full-blown or it may occur suddenly.

In anger, changes occur in all three major facial areas: eyebrows, eyes, and the mouth. There is ambiguity in recognizing anger unless all three facial areas are involved. Anger's eyebrow has common characteristics with the fear brow. In both cases, the inner corners of the eyebrows are drawn together. However, for fear the eyebrows are raised while in anger, the eyebrows are lowered; and may actually appear to be angled downward or just to be lowered in a flat fashion. In the eye area for anger, the eyelids are tensed and the eyes are staring. The anger mouth has two basic types: a closed, lip-pressed-against-lip mouth, and the open, square mouth.

The following points describe the manifestation of anger in each of the three facial areas:

- Lowered and drawn together brows
- Vertical lines show between the brows
- Tensed lower lids, which may or may not be raised
- Tensed upper lids, which may or may not be lowered by the action of the brows
- A hard stare in the eyes sometimes with a bulging appearance
- Two basic lip positions are common in anger: pressed firmly together, with the corners straight or down; or open, tensed in a squarish shape as if shouting.
- Dilated nostrils, which are not essential to the anger facial expression and may appear in sadness as well

2.1.5 Joy

Ekman characterizes pleasure with positive physical sensations and considers the position of lips the major cue for determining the intensity of joy. But the lip position is usually accompanied by the deepening of the naso-labial fold and more pronounced lines under the lower eyelid (Figure 1-e).

Joy is noticeable in the lower face and lower eyelids:

- Corners of lips are drawn back and up.
- The mouth may or may not be open, with teeth showing or not.
- A wrinkle (the naso-labial fold) appears from the nose to the outer edge of the lip corners.
- Raised cheeks
- Wrinkles below the lower eyelids, which may be raised but not tense.
- Crow's-feet wrinkles showing in the outer corners of the eyes

For low intensity joy, the mouth is usually closed, the teeth are not exposed, and the lower eyelids are not raised. For high intensity joy, it is usually the opposite.

2.1.6 Sadness

Sadness (Figure 1-f) is a passive feeling associated with quiet suffering. The intensity of sadness can vary from slightly sad (feeling gloomy) to extreme cases during mourning. The amount of facial involvement in sadness directly corresponds to the intensity of the sadness. The facial cues to sadness are:

- The inner corners of the eyebrows move upward.
- the inner corners of the eyebrows are raised and the skin below the eyebrow is triangulated
- The inner corner of the upper eyelid is raised.

- The corners of the lips are lowered or the lip is trembling.
- gaze is often down
- Lower eyelid not raised in the low intensity

Raising the lower lid increases the sadness conveyed and the sadness mouth is most often confused with a disgust-contempt mouth.

2.2 Facial Expressions and Expressiveness

In general, past studies on expressive facial movements have focused on two areas: 1) creating more expressive representations of the six basic expressions proposed by Ekman(Pandzic & Forchheimer, 2002; Ruttkay, Noot, & Ten Hagen, 2003; Tsapatsoulis, Raouzaiou, Kollias, Cowie, & Douglas-Cowie, 2002) and 2) creating a wider range of facial expressions, known as complex expressions.

A number of different approaches to creating facial expressions were developed in an effort to make facial expression including the six basic expressions more plausible. Some of these main approaches are discussed in the following section.

2.2.1 Different Approaches to Computational Facial Expressions

There are a number of approaches to creating facial expressions including blend shape-based, parameterization, psuedomuscle-based, muscle-based and performance-driven approaches.

In the blend shape-based approach, new facial expressions are made as a combination of a set of existing expressions. This can be done by interpolating between facial expressions on a head model (Pighin, Hecker, Lischinski, Szeliski, & Salesin, 2006; Q. Zhang, Liu, Guo, Terzopoulos, & Shum, 2006) or interpolating between facial expressions in images(Blanz & Vetter, 1999; L. Zhang, Snavely, Curless, & Seitz, 2007). The simplest form is linear interpolation; however other functions such as cosine or spline interpolations are also used for acceleration/deceleration effects at the beginning and end of an animation. The interpolation techniques correspond to key-framing approach in animation. Joshi, Tien, Desbrun, and Pighin (2005) proposed a segmentation-based version of this approach, which divides a face model into small regions and applies the blending to each region. This approach helps with handling specific parts of a face without affecting other irrelevant parts, thus it preserves the significant amount of the complexity of human expressions (Joshi et al., 2005). A general drawback of this approach is that it needs the user/animator to create all keyposes/blendshapes. The final animation strongly depends on the plausibility of the blendshapes (Parke, 2006). As an additional drawback, Image based methods in this approach have to exploit a way to identify facial features in images.

In the parameterization approach face features and possible facial movements are defined as a set of parameters in a way that each possible facial configuration can be uniquely defined by specifying the values for the parameters, although a complete set of parameters has yet to be developed (Parke, 1974, 2006). One problem with the existing sets is the dependencies between parameters and their overlaps in terms of facial regions they cover or move. In this regard, if a conflict occurs between two or more parameters, an unnatural expression might be the result (Deng & Noh, 2007; Waters & Frisbie, 1995). Another problem of this approach according to Deng and Noh is that the choice of parameters depends on the mesh topology and therefore a generic parameterization might not be possible (Deng & Noh, 2007). Both of these shortcomings have been addressed by newer hierarchical parameterization techniques that use object oriented hierarchical unitized parameters to deal with the unnatural expression problem and MPEG4 facial regions to deal with the generic mesh problem (Arya & DiPaola, 2007; Arya, DiPaola, Jefferies, & Enns, 2006; DiPaola & Arya, 2004a, 2005).

Pseudo muscle-based animation uses a relatively small number of control parameters that can mimic the behavior of facial muscles. The most well-known techniques in this approach are Abstract Muscle Action (AMA) procedures and the Free Form Deformations (FFD). The AMA procedures are usually more complex than parameters in the parameterization approach and were designed based on the FACS action units. Each AMA procedure approximates the action of one or a group of related muscles. For example, “move right eye vertical” is an AMA procedure, which emulates the action of a group of muscles responsible for the vertical movements of the right eye. The definition of the higher level parameters such as emotions and phonemes on top of the AMA procedures has lead to more efficiency in making facial animations with this approach. In the Free Form Deformation (FFD) approach, a surface region with the appropriate control points is defined for each muscle action. Actuating a muscle corresponds to displacing a control point which changes the appearance of the surface region and the face. In these approaches, animator can create facial expressions by modifying these higher level construct or pseudo-muscles. This has two advantages compared to modifying 3D meshes; first, animator does not need to move individual mesh vertices. Second, pseudo muscles ensure that movement is only propagated through the relevant areas of the face which prevents the creation of bizarre facial configurations.

In the muscle-based approach, mathematical and physical equations are used to define the movements of the face muscles and the inter-muscle interactions. In contrast to pseudo-muscle approach, facial tissue dynamics are usually simulated in this approach (Waters, 1987; Waters & Terzopoulos, 2002). The early muscles defined by Platt and Badler were based on a mass-and-spring model (Platt & Badler, 1981). Later, Waters developed a muscle model with two types of muscles: linear muscles that pull and sphincter muscles that squeeze. His model was also based on the mass-and-spring model but he used directional vectors for simulating the function of muscles (Waters, 1987). Others have expanded the muscle-based approach by including models of skin and facial tissues (Terzopoulos & Waters, 1990; Waters & Terzopoulos, 2002). This approach can be combined with parameterized techniques where the parameters can control muscle groups as well as other effectors.

A somewhat different approach to facial animation is the performance-driven approach in which the movement of facial features on a real face are transferred to a synthetic face (Williams, 2006). This transfer can be from tracking features of a face in a video sequence (Waters & Terzopoulos, 2002) or from a live performance (N. M. Thalmann, Cazedevals, & D. Thalmann, 1993). Motion capture (Guenter, Grimm, Wood, Malvar, & Pighin, 1998) is a type of performance-driven approach in which the captured movement data are pre-processed before transferring to the head model. Voice driven animation is another type of performance-driven animation in which the movements of the face are determined based on the qualities of an input audio stream (Arya & DiPaola, 2007; DiPaola & Arya, 2004b; Morishima, Aizawa, & Harashima, 2002).

2.2.2 Emotional Spaces

As indicated in section 2.2, a group of studies seek to widen the range of expressions displayed by a virtual character (Albrecht, Schröder, Haber, & Seidel, 2005; Mancini, Hartmann, Pelachaud, Raouzaiou, & Karpouzis, 2005; Tsapatsoulis et al., 2002). This group of studies usually exploit an emotional model developed by psychologists and provide a mapping between facial configurations and the points in the emotion space. The most well-known emotional models are Plutchick's emotion wheel, Whissel's two-dimensional emotion model (1989b) with activation (arousal) and evaluation (valence) axes (Garcia-Rojas et al., 2006; Latta, Alvarado, Adams, & Burbeck, 2002; Raouzaiou, Karpouzis, & Kollias, 2003; Tsapatsoulis et al., 2002), and three-dimensional model with pleasure (valence), arousal, and dominance (power) axes (Albrecht et al., 2005; Becker & Wachsmuth, 2006).

Plutchick (1980) proposed a three dimensional circumplex model for the emotions. The vertical axis of the cone demonstrates intensity. Eight sectors of the cone represent eight primary emotion dimensions, in four pairs of opposites: joy and sadness, acceptance and disgust, fear and anger, surprise and anticipation; the emotions in the blank spaces between each two sector represent the mixture of the two surrounding emotions. In terms of positive and negative emotions, Plutchick's circumplex is more balanced than Ekman's six emotions and has been used as the underlying emotional space for many studies (Albrecht et al., 2005; Tsapatsoulis et al., 2002).

Whissel's two-dimensional emotion space (1989b) is composed of activation (arousal) as the vertical axis and evaluation (valence) for the horizontal axis. The activation axis represents the tendency of a person to take some action rather than none while the evaluation axis corresponds to the negative/positive evaluation by the individual about the situation. The full-blown emotions form a circular pattern around the center of the space which is consistent in shape with Plutchik's wheel.

Pleasure-Arousal-Dominance (PAD) is another emotion space that captures a wide range of emotional states and was proposed by Mehrabian (1996) based on empirical data. Two of the three dimensions of the space correspond to pleasure (valence) and arousal (activation) similar to the two-dimensional model, while the last axis belongs to dominance/control (power) which represents the perceived control/influence in a situation by the individual.

Stoiber et al. (2009) suggested another two dimensional control space for manipulating facial expressions on a synthetic face. They argued that previous parameter sets for the face are generally large, complex and can lead to unnatural facial expressions. In addition, efficient use of those parameters requires hours of practice; thus, they are not suitable for automatic generation in interactive scenarios. Using a computer vision algorithm, they defined a statistical model of facial expressions based on a database of facial movements displayed by an actor. As a result, the generated facial space does not include any unnatural facial expression. The proposed 2D space was a pie chart with six colour sections corresponding to the six basic expressions. The resulting 2D control space is very similar to Plutchik's emotion wheel. The main difference is that this model is based on the actual deformation data instead of theoretical considerations. However, it could be seen as a validation for the emotion wheel.

Other than the choice of an emotional space as a reference, researchers are also different in their approach for associating a facial configuration to an emotion/meaning. Smith and Scott suggested that in general, there are three approaches to attribute meaning to facial expressions: 1) the purely categorical model, 2) the componential model, and 3) the purely componential model (Smith & Scott, 1997). The categorical approach is based on Ekman's findings and only deals with a limited number of full face patterns; in this approach, a meaningful unit is a full face. In contrast, in the componential and the purely componential models an Action Unit (AU) is a meaningful unit. These two models differ in that the purely componential model considers the meaning of the full face pattern as the sum of meanings of its components while the componential model, suggested by Smith and Scott (1997), states that such an assumption is not always true.

2.2.3 Expressive Facial Movements Using Emotional Spaces

Using an underlying emotional model, different researchers tried to define a mapping between points in the emotional model and facial configurations. Most previous studies have used blending methods and algebraic models to derive new expressions from a set of predefined expressions. Tsapatsoulis et al. (2002) create mixed facial expressions by interpolating eight facial expressions as starting points. The parameters for the interpolation are the similarity of the emotion to the eight base emotions and the intensity of the emotion. They used Plutchick's emotion wheel (1980) for finding the similarity of emotions placed around the emotion wheel and Whissell's rating of the emotion (1989a) for determining the position of the mixed emotion in accordance to the activation and evaluation dimensions. In their model, the activation value is a measure for the intensity of the emotion.

Albretch et al. (2005) followed a similar approach but used the three-dimensional emotion space (PAD space) and consider the six basic emotions introduced by Paul Ekman as starting points of the interpolation. Moreover, they integrated a text-to-speech system based on the same emotional model into their system to create an expressive conversational agent. Arya et al. used the same three-dimensional space (activation, evaluation, power) for emotions and conducted a user study to find the correlations between Facial Animation

Parameters (FAPs) and the emotion dimensions (Arya, DiPaola, & Parush, 2009). Based on the results of the study, they provide a set of fuzzy rules for activating action units in each region of the emotion space. As they investigate the affective impact of each Action Unit, their work belongs to the componential approach. This is one of the few works that did not use blending for making complex facial expressions.

Byun et al. (2002) introduced four high level parameters called FacEmote for modifying the expressiveness of an input facial animation sequence. The proposed set of parameters is an extension to Emote parameters for expressive hand and body gestures (Allbeck & Badler, 2002a, 2002b; Chi, Costa, Zhao, & Badler, 2000). Emote and FacEmote parameters are derived based on the Laban Movement Analysis (LMA) system and qualitatively modify an animation sequence. While a preliminary evaluation were conducted on the effectiveness of Emote (Chi et al., 2000), FacEmote has not been the subject of any studies.

The proposed model by Martin, Niewiadomski, Devillers, Buisine, and Pelachaud (2006) falls in the componential approach; they define complex emotions as either the combination of more than one emotion or a modified emotion based on social considerations. Therefore, a complex emotion can be fake (showing an expression of an unfelt emotion), masked (masking a felt emotion by an unfelt emotion), superposed (showing a mixed of felt emotions), inhibited (masking the expression of emotion with the neutral expression), suppressed (de-intensifying the expression of an emotion), or exaggerated (intensifying the expression of an emotion). To form a complex emotion, first they partitioned the face into eight regions; the output expression was obtained by combining the facial regions of the input expressions based on the type of the complex expression. They used their model for complex facial expressions and gestures to replay the upper body movements from a fully annotated video corpus on the Greta agent.

Using the above definition for a complex facial expression, Bevacqua, Mancini, Niewiadomski, and Pelachaud (2007) propose an architecture for an Embodied Conversational Agent (ECA) called Greta (Ochs et al., 2005; Pelachaud & Bilvi, 2003). Greta receives a text tagged with communication and expressivity descriptors as input and is capable of generating both simple and complex expressions. A head/gaze/face computation module is responsible for creating appropriate facial expressions and head movements. During the process, this module might call another module responsible for computing complex facial expressions. The output of the system is an animation file that contains Facial Animation Parameter (FAP) values for the animation frames. Expressiveness of Greta can be modified qualitatively using six parameters: overall activity, spatial extent, temporal extent, fluidity, power, and repetitiveness. The ECA exploits a mutually-consistent Head and Gaze module that modify the head and gaze movements using those qualitative parameters. The complex expressions are obtained from the six basic expressions. For this purpose, the expression generation module either uses the predefined rules or calculates the fuzzy similarity based on visual resemblance between expressions.

Arya, Jefferies, Enns, and DiPaola (2006) investigated the link between facial movements and the personality assigned to a virtual character in a user study. In their study, the facial movements include facial expressions, 3D head movements, nodding, raising/lowering/squeezing eyebrows, gaze shift, and blinking. Subjects watched short animated sequences with a character showing facial movements and rated the personality of the character on a standardized adjective list. Then, Arya et al. (2006) mapped the responses on the Wiggin's circumplex personality model(Wiggins, Trapnell, & Phillips, 1988), which consists of two dimensions of: 1) desire for affiliation and 2) displays of social dominance. The results suggested that people associate dynamic facial actions such as head tilting and gaze aversion with the dominance dimension, while the facial expressions of contempt and smiling affected the subjects' ratings along the affiliation dimension. In addition, the characters with higher frequency and intensity of the head actions were perceived as being more socially dominant. Data from this study were also translated to the Five Factor Model (FFM) for personality consisting of Openness, Conscientiousness, Extraversion, Agreeableness, and Neuroticism (also known as the OCEAN model)(Zammitto, DiPaola, & Arya, 2008). In addition, the results of the study has been integrated into a facial animation authoring tool (iFace) that we utilized for making the animated sequences for our studies (Arya & DiPaola, 2007; Arya et al., 2006).

An in-depth survey on virtual characters, personality and emotion models as well as facial expressions has been conducted by Vinayagamoorthy et al. (2006). Pelachaud (2009) published another comprehensive survey of past techniques on creating facial expressions for virtual agents especially embodied conversational agents. The survey summarizes previous studies in this area together with a description of the exploited emotional model and/or their general approach for creating complex expressions.

Although these studies have enhanced expressiveness of the created facial expressions, a concrete computational model for making complex facial expressions and emotions has not been developed yet.

2.3 Non-Photorealistic Rendering

Non-Photorealistic Rendering (NPR) is a computer graphics technique inspired by painting, drawing, technical illustration, and cartoons. In contrast to other computer graphics techniques that focus on making photorealistic outputs, an NPR algorithm modifies the photorealistic input imagery into a naturalist rendering style such as cartoons, paintings or drawings, depending on the application. Thus, different elements of the scene in a non-photorealistic rendering can convey different amount of information; certain elements can be emphasized while others are abstracted. Non-photorealistic rendering includes a wide range of styles such as painterly, pen-and-ink illustrations, technical illustration, and cartoon style. The focus of this work is on painterly or stroke-based rendering, which typically uses a 2D source such as a photograph and creates a list of strokes to be rendered on a new canvas (see Figure 2).

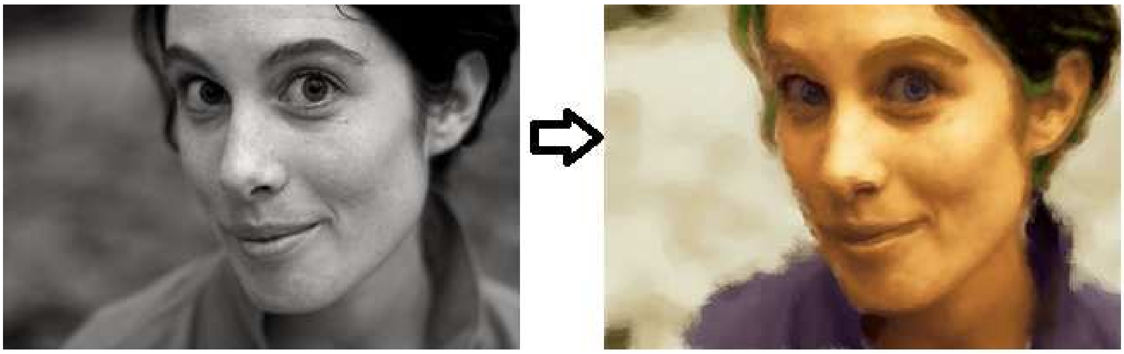

Figure 2- Example input and output for an NPR process (painted by the Painterly program)

The basic elements of painterly rendering are brush strokes and a virtual canvas; Brush strokes contain a set of properties (e.g. size, colour, orientation) and are placed on a virtual canvas in a predetermined order to generate a painting of the input photograph. NPR painterly styles are as diverse as painting styles used by artists of different eras, but the majority of work was done on impressionism (Healey, Tateosian, Enns, & Remple, 2004; Litwinowicz, 1997; Meier, 1996) and to a lesser extent on other styles such as pointilinism and expressionism (Klein, Sloan, Finkelstein, & M. F. Cohen, 2002).

The following sections give an overview of previous painterly work on images and video (section 2.3.1), use of NPR in interactive applications/art installations (section 2.3.2), and affective studies in colour and NPR (section 2.3.3).

2.3.1 Painterly Images and Video

NPR techniques were originally proposed for images. Especially painterly style is largely an attempt to mimic the work of painters. This style was first proposed by Haeberli in 1990 who introduced painting using an ordered collection of strokes described by size, shape, colour and orientation (Haeberli, 1990). Based on his work, Litwinowicz (1997) developed an algorithm to generate paintings of the input images. Later, Hertzmann (1998, 2001) proposed a multi-pass approach of painting using coarse to fine brush strokes. His work advanced the field by inspiring from the actual process of painting. After that, a number of mostly computer vision techniques enhanced both the underlying algorithm and aesthetics of the output. Gooch and Gooch (2001) introduced the idea of dividing the image into homogeneous grayscale regions to reduce number of required brush strokes.

DiPaola (2002a, 2002b, 2009) proposed a cognitive based parameterized painterly system for creating portrait paintings from the input photographs. The program was developed based on a qualitative knowledge space built out of art books and interviews with painters, which then filtered through knowledge of human vision and cognition. The set of painting parameters such as brush stroke properties and the number of passes and the rendering technique are provided as an xml file. Their system builds on the Hertzmann's multi-pass technique but it also benefits from the cognitive studies on the human vision system, and the knowledge space of faces and facial features. Thus, the system is capable of making more expressive portrait pictures compared to a general painterly system. Santella and DeCarlo (2002, 2004) suggested a content-based approach for choosing the brush properties for the elements of the scene. They used an eye tracker to identify the salient segments of the input image. Based on the obtained saliency map, the algorithm applied more and finer brush strokes in the regions of more interest. More information about stroke-based rendering could be found in Hertzmann's survey (2003).

Painterly video is the logical offspring of painterly images and although it was introduced over the last decade, it has received considerable attention by researchers. According to Hertzmann and Perlin (2000), there are two general approaches to creating NPR videos: 1) in the first approach, the video represents a painted world; therefore, brush strokes, in this approach, are usually attached to geometric objects (Daniels, 1999; Meier, 1996). The algorithms for this approach usually propose a method to manage the density of strokes as the objects move closer or farther to the camera. 2) the second approach for NPR videos corresponds to painted representation of the world, in which brush strokes are detached from geometric objects in time and space (Curtis, 1998; Hertzmann & Perlin, 2000; Litwinowicz, 1997). Videos based on this approach can flicker because of lack of temporal cohesiveness. For example if the directions of brush strokes vary significantly in the subsequent frames without any knowledge passed from one frame to the next.

In the first approach mentioned above, a set of particles are attached to scene objects with each particle representing one brush stroke. A well-known work in the particle approach is the work of Meier (1996) (from Walt Disney Feature Animation), who use normal vectors of geometric objects for determining brush stroke orientation. Some strokes had colour, size, orientation and other parameters assigned to them which then were used for rendering; otherwise a reference image was used to obtain the values for those parameters. Her work is interesting because she looked at the problem from a practical perspective and suggested a list of best practices based on the aesthetics of the final results. However, attaching particles to objects introduces the problem of appropriate density for the particles. Thus, a method is required for handling the density through the animation. This problem arises when moving an object, especially changes in the distance, causes the particles to be too dense or far apart; this results in artificial, unpleasant looking scenes (Cornish, Rowan, & Luebke, 2001)

To address the particle density problem associated with the first approach, Cornish et al. (2001) use a hierarchical view-dependent approach. Their method is inspired by and built upon algorithms for view-dependent polygonal simplification. A densely sampled polygonal model was used for each object; with each vertex of the model representing a particle. The number of vertices was adjusted (increased/decreased) based on the distance and other view properties. This approach also allows different levels of detail in different areas of the scene.

The common issue associated with the videos of the second approach mentioned above, is flickering which arises when successive frames of a video are painted separately using different number, different orientations or different sizes for brush strokes in one region within those frames. In fact, the number, size and orientation of brush strokes directly impacts temporal coherence of the final video. Of these factors, at least controlling cohesiveness of the orientation would significantly reduce the frame-to-frame flicker. Therefore, one could considerably mitigate the problem by using appropriate orientations for brush strokes throughout the video. Daniels (1999) was the first person to introduce using optical flows for the orientation, which then became a common approach in the field; most of the later work, addressed the problem by using vector fields that are defined either manually (user-specified) or automatically (using normal vectors and curvatures of geometric objects) (Hays & Essa, 2004; Hertzmann & Perlin, 2000; Litwinowicz, 1997; Park & Yoon, 2008; Snavely, Zitnick, Kang, & M. Cohen, 2006).

An improved version of vector fields was introduced by Klein et al. (2002); they defined a set of functions, rendering solids, which span over time. Their approach is applicable to more painterly styles than just impressionism such as cubism and recent abstract styles.

Hayes and Essa (2004) enhance spatio-temporal consistency of painted videos by assigning temporal constraints to other properties of brush strokes such as colour and size. They use a dynamic set of brush stroke properties that gradually changes based on image and motion properties. Radial Basis Functions (RBFS) were used to orient brush strokes over time and space. In addition, edge detection techniques, decoupling output resolution from the input dimension, and use of brush stroke textures and simple lighting model improves the output video. Since then, other researchers tried to further enhance the results or apply other styles such as watercolourization on the videos (Bousseau, Neyret, Thollot, & Salesin, 2007)

Snavely, Zitnick, Kang, and Cohen (2006) use depth information together with data from 2D sequences (they call it 2.5D video) to achieve temporal coherence in the painted output sequence. Such depth information can be captured using a special camera. However, the captured data even with a special camera has a lot of noise. Sanvely et al. (2006) decrease the noises by applying filters to the depth information of the input frames. Depth information does not provide complete 3d information over time but they introduce techniques for calculating normal and surface direction at each pixel and use these normal vectors to determine the orientations of brush strokes. The generated videos in two NPR styles, cross-hatching and painterly rendering, show the appropriateness of their approach.

2.3.2 Interactive NPR

Some other studies were more concerned with using NPR in an interactive context. Hetrzmann and Perlin (2000) were two of the first researchers who worked on painterly videos. In Hertzmann's algorithm for painting still images, each pass of the painting only paints areas of the current output which are different from the original frame. Using the same system for painterly videos, they painted the new frame over the previous frame only when there is a considerable change between the two frames; they warped the previous brush strokes towards the new output and used optical flow to determine the orientations of strokes. The result is similar to the paint-on-glass style. Based on their observations, in 30 Hz painterly videos, even a little flickering is noticeable. Moreover, 30Hz frame rate appears as an ordinary video with bad artefacts rather than a moving painting. Therefore, he suggested 10-15 frames per second. In the interactive demonstration of their work, videos of users were painted at 1-4 fps frame rate, users were mainly positive and attracted to the work.

Olsen, Maxwell, and B. Gooch (2005) presented a technique in which casual users could interact with the system to create images/videos in the expressionist style. Each frame is segmented to a set of regions which is also modifiable by the user, and then the user can assign brush properties (e.g. colour, size, etc.) to each region by choosing from a set of configuration files or by creating a new one. They proposed to use different brush configurations and vector fields for different segments of a frame and also to use both fluid simulations and RBFS, and even a hybrid approach to define motion fields, an approach that they found very useful for mitigating the flickering problem in the output video.

2.3.3 Affective Studies in Colour and NPR

The Munsell colour system was proposed by Albert H. Munsell in the first decade of the 20th century. The colour space is formed by three independent dimensions of hue measured by degrees around horizontal circles, value (brightness) measured vertically from 0 (black) to 10 (white), and chroma (saturation) measured radially outward from the neutral (gray) vertical axis. The spacing was determined based on perceptual characteristics of human beings. In this system, there are five principal hues: red, yellow, green, blue, and purple, along with five intermediate hues, which are halfway between adjacent principal hues. *Value*, or brightness, varies vertically from black (value 0) at the bottom, to white (value 10) at the top. Chroma is measured along the radius from the centre of each slice, and represents the “purity” of a colour, with lower chroma being less pure.

Closely related to but a more advanced colour system compared to the Munsell colour system, is the CIELAB (*La*b**) which we used in the later user studies (third pilot study and final study). In the *La*b** system, the *L* component represents lightness while *a* and *b* characterize the colour components. The system approximates human vision. *L=0* is black while *L=100* is diffuse white. *a** component represents colours from green (negative values) to magenta (positive values) and *b** varies between blue (negative) to yellow (positive). The Painterly system used for our work, uses CIELAB colour system internally, to better approximate painters human vision and perception.

Past researchers investigated the relationship between colours and emotions (Boyatzis & Varghese, 1994; Kaya & Epps, 2004; Shugrina et al., 2006; Terwogt & Hoeksma, 1995; Valdez & Mehrabian, 1994). Most of them used fully saturated natural colour stimuli on a gray background. The meaning of the colours could be different based on the context; as an example people associate red to both love and anger. Thus, the result of applying these abstract studies to different contexts is not always predictable. Moreover, most of the studies asked the participants to indicate the feeling they associate with a colour, but the conscience colour association (subjective data) could be different from the task-based (objective) data (Wallraven, Bülthoff, Cunningham, Fischer, & Bartz, 2007).

In a study of 98 college students, Kaya and Epps (2004) investigated emotional responses to five principal hues, five intermediate hues, and three achromatic colours (black, gray, and white) in the Munsell colour system.

According to the results, the majority of responses were positive for principle hues and negative for achromatic colours. More specifically, green was strongly associated with positive adjectives such as calmness, relaxation and peace; yellow to happiness and excitement. Then blue, red and purple were considered positive respectively. In that study, people described blue with positive adjectives such as calmness, happiness, and peace and also to a lesser extent with negative adjectives such as sadness, depression, and loneliness. Red was also described both positively (e.g. love, and romance) and negatively (e.g. fight, and blood). For intermediate hues, blue-green was perceived as the most positive one, followed by red-purple, yellow-red, and purple-blue. The yellow-green intermediate hue was mainly associated with negative feelings such as sickness, disgust. For achromatic hues, white is considered positive while black and gray were mainly reported with negative adjectives. The results of their study clearly show the diversity among people in colour-emotion association.

Another study by Terwogt and Hoeksma (1995) examined the possible relationship between an individual's colour preferences and his/her colour-emotion association. They found a correlation between colour preferences and emotions. They concluded that for younger groups (7-year-old and 11-year-old children to a lesser extent) colour-emotion association has a strong link to emotion and colour preferences, while for the adults there was not such a correlation between colour and emotion preferences and subjects colour-emotion association.

Valdez and Mehrabian (1994) associated vague and contradicting (conflicting) results in the past colour studies to their methodological problems. They claimed that a common problem of the past studies is inadequate specifications or controls of colour stimuli such as absence of controls for saturation and brightness while investigating effects of hue and use of non-standard or unspecified lighting conditions. Another common issue is lack of good measures for emotional responses to colour stimuli (e.g. using adjective lists without enough validity/reliability). Controlling for the above factors, they conducted three user studies; the first study was on the emotional impact of colour saturation and brightness using five principle hues and five intermediate hues in the Munsell colour system. They used Russell and Mehrabian's verbal-report Pleasure-displeasure, Arousal-nonarousal, and Dominance-submissiveness (PAD) for measuring responses (1977). Based on the results of this study, they found three linear relationships between PAD dimensions and brightness/saturation, realizing that these two factors (brightness and saturation) significantly affect emotions. Moreover, they found that brightness has a stronger impact compared to the saturation. Also, female vs. male association of brightness/saturation to emotions in PAD space were similar. However, women were more sensitive in terms of their emotional reactions to brightness and saturation. In the second study, they focused on the impact of hue on the emotional responses of users. The overall association of hue to PAD ratings was found to be weak; however, the results indicated that pleasure levels for blue, blue-green, green, red-purple, and purple were significantly greater than those for green-yellow, yellow, and yellow-red. In addition, the green-yellow hue was significantly rated more dominant and arousing. For the last study, they examined the emotional impact of achromatic colours (black, three grays, white) and found a second order relationship between brightness and PAD (pleasure/arousal/dominance) values. They concluded that their findings are consistent with previous studies that linked warm colours (high saturation, low brightness) to higher arousal in comparison to cool colours (low saturation, high brightness) which is associated with less arousal.

A study by Henver (1935) explored the affective content of red and blue colours as well as different shapes such as circles, squares, sharp angels and waves used in a painting. Their study composed of two parts: abstract designs and portraits. For the first part, they asked a number of art students to create abstract paintings in different colours and shapes. Then, they asked a number of undergraduate students to choose their feelings from a list of adjectives after watching each art work. Henver's study (1935) is closely related to this work in the sense that the colours and shapes were part of a painting rather than isolated colours/shapes displayed to participants. According to their results, blue is expressive of dignity, sadness, tenderness, and red is quite decidedly expressive of happiness, restlessness and agitation. Moreover, they found out that curves are tenderer, and sentimental compared to the straight lines that are more serious, vigorous, and robust. Straight lines have a tendency toward sadness and dignity whereas curves are more serene, and playful graceful. Repeating the study for portraits, they found little difference in the suggestive meaning of straight and square lines as well as curves for the two studies. Finally, they found that the combination of angles which are happy and restless, with the colour red, also happy and restless, makes the most clear-cut and definite of any response in the series.

Expanding the notion of computational creativity to NPR systems, Colton et al. (2008) designed an interactive system that paints the portrait of a person based on his/her emotional state. The purpose of their work was to develop an automated painter which exhibits creative behaviour such as choosing appropriate painting parameters for a given subject matter. Their system is composed of an expression recognition system which detects one of Ekman's six basic emotions and an expert system which determines the style and parameters for the painting. They used the following parameters for each emotion: for anger, green for face and red for around the eyes were used with lines instead of curved segmentation style, grayish colours were assigned to disgust, fear was associated with cool hues such as blues and grays while happiness with very vivid colour palettes. For sadness, they considered a small palette of muted colours, and for surprise, an abstracted background; with a rendering style that suggests explosions. They made an online gallery from the outputs of their system ("The Painting Fool - A Computer Artist?," 2010).

A similar system by Shugrina et al. (2006) changes the style of a given painting in real-time based on the user's emotional state. Their system is also composed of two parts: 1) an emotion recognition part, which uses computer vision techniques to recognize user's emotional state based on Plutchick's pleasure-arousal emotional space, and 2) a painterly rendering part that changes the painting style and colours based on a set of parameters. They defined a mapping based on previous psychological studies. Their mapping mainly associates pleasure with brightness and arousal with saturation and hue. Another parameter of the output paintings is stroke denotation style. This parameter generally varies along pleasure and arousal dimensions from sloping, which denote serenity, laziness, and tender-sentimentality, to harsh-angled, and jaggy, denoting vigorousity and power. The number of different painting styles for the system is limited to the system's capability for recognizing emotional states. In a public demonstration of the system, users' feedback was positive in terms of painting aesthetics and method interaction. In addition, the method of interaction was determined intuitive and easy to use for users in comparison to using sliders to get similar paintings.

In a recent work, de Melo and Gratch (2009) used an interactive Genetic Algorithm (GA) approach to investigate the colours suitable for the expressions of joy and sadness. In the first study with the GA system, users guided the evolutionary process by rating the choice of colours for lights and filters on a character's face. In the second study, de Melo and Gratch examined the features of the images created by users in the first study in terms of their colour properties. The results exhibited that images of joy had more colours and were brighter and more saturated than the images for sadness. Their work is similar to ours in the sense that they also apply lights and filters to a character's face. However, because of using a partially random process (GA) and using lights the resulted images are less plausible. We believe a similar evolutionary process for developing the appropriate colour palettes could reach more visually plausible results.

B. Gooch, Reinhard, and A. Gooch (2004) conducted a number of user studies to investigate the recognition and learning speed and accuracy for three visual styles: 1) people's photographs, 2) black and white illustrations, and 3) caricatures. The results of the studies indicated no effect on recognition speed and accuracy or learning accuracy for the three styles. However, learning speed for illustrations was two times less than for photographs and it was 1.5 times less for caricatures.

Wallraven et al. (2007) investigated the effect of three stylization techniques and computer graphics style on computer-generated and real-world video of facial expressions. They used four different styles: standard avatar, brush-stroke, cartoon and illustrative stylization, and three levels of detail for each expression and stylization type in their study. Subjective, questionnaire data as well as objective, task-based data were gathered for the analysis. The subjective data was the result of showing stylized sequences to participants side by side and asking for the one that captures the essence of the expression better. For the task-based evaluation, they measured recognition performance (recognition accuracy and time), perceived intensity, and perceived sincerity. Moreover, a final questionnaire collected the users' rankings for the three styles based on aesthetic principles, effectiveness for rendering facial expressions and subjective preference separately. Based on the results, brush stroke stylization was the worst in terms of effectiveness, recognition accuracy, intensity and even subjective preference. However, the brush stroke pictures that they provided were very blurry, and without enough details in important areas such as eyes, so we believe their result can partially be confounded by their method for making brush-stroke pictures. The concluded that one of the most important outcomes of their work was that the introspective and task-dependent measures do not always correlate.

Duke et al. (2003) investigated the affective qualities of images to provide suggestions for computer graphics (Halper et al., 2003). They conducted a series of experiments to show that different elements of NPR illustrations could affect users' feelings. Some of the results of their experiments show that: 1) NPR can be used to induce perception of safety/danger; people associated jagged outlines to danger whereas they perceived straight outlines as safe, 2) NPR can affect interpersonal relationships; in another experiment, people associated line thickness, and continuity to character strength, and 3) NPR can influence both navigation and exploration behaviours; subjects in their experiments tended to choose paths with higher levels of visual details. They concluded that psychological theories and studies can be used to enhance the outputs of NPR applications; and moreover psychology and NPR can mutually benefit from such interaction.

Recently, da Pos and Green-Armytage (2007) conducted a study among European and Australian designers to determine if there is consistency among people in associating colours with facial expressions. Two groups of young (22 subjects around 25 years old) and slightly older (16 subjects around 25 years old and 6 subjects around 45 years old) designers were asked to choose first, a combination of three colours and then, a single colour that best fit each of the six basic expressions. The two groups used very similar colours. Looking at the lightness component of the chosen colour in *La*b** space, subjects used very light colours for happiness, surprise and fear, medium lightness for sadness and disgust, and dark colours such as red and black for anger. In terms of saturation, the colours chosen for fear and sadness were mostly desaturated while happiness, surprise and anger colours were highly saturated. Participants mostly used colours from the yellow-red quadrant, which is suggestive of the association between active emotions and warm appearance. A great percentage of the participants used black for anger; for surprise and happiness, they mostly chose orange hues. Then they used the set of three-colour combinations and asked the participants to associate a facial expression with each combination. In this way, they tried to examine whether the face-colour-face conversion shows that designers can communicate in the abstract language of colours and faces or not. In most cases, the assigned facial expression to the three-colour combinations was the same as the initial facial expression. While our work follows similar lines of interest with this study, there are major differences between our study and theirs. First, they used static images of the full-blown expression but we are interested in the perceived effect of colours in a dynamic sequence. Second, they asked for the conscious association of colours while we are interested in discovering the unconscious effect of the colour palettes on their perception.

While their works shows association of the chosen colours with the facial expressions, it is unknown whether using those colours affects the way the expressions are observed or not. Third, designers were the subjects of their study while we did not focus on subject from a specific field such as design or art. Last but not the least, we used the colours proposed by da Pos and Green-Armytage for each facial expression and investigated the effect of that colour palette on the perceived intensity of that expression. However, their work informs our research, as the colour that people associate to a facial expression is more likely to be the colour that boosts the effect of that expression.

DiPaola et al. conducted a series of controlled studies to prove that Rembrandt exploited textural variation (textural agency) to guide the viewers' gaze (DiPaola et al., 2010). More specifically, they used an eye tracker to examine the impact of a number of painting techniques such as textural variation/agency and lost and found edges on the pattern of gaze movements in viewers. The initial material for all experiments were based on four of Rembrandt's portrait paintings; they took photographs of four human models who were dressed and lit in a similar fashion, and then used a parameterized painterly program(DiPaola, 2007a, 2007b, 2009) to render it in Rembrandt's style. Textural details of the portraits were modified in four regions: one region centred on each eye and one region centred on each side of the chin. Using the original Rembrandt paintings, the generated portraits and some filler paintings, they tracked viewer's eye movements during the first round of viewing images. During the second round, the participant ranked the images based on perceived artistic merit. The focus of the first experiment was on the patterns of eye movements for the generated paintings compared to the original photos. Results of the eye-tracking data indicated that people's gaze move less when viewing paintings compared to when they are viewing the photographs. In the second experiment, they captured the pattern of viewers' eye movements looking at Rembrandt's work and the automatically generated portrait paintings. In addition, they asked the participant to choose one of four variations of the generated portraits to ensure his/her sensitivity to the modifications. The third experiment examined the effect of textural highlights on viewers' eye movements and the associated artistic rating. The results confirmed the effect of textural variation and textural highlights on the pattern of eye movements. More specifically, subjects' eyes went to the detailed eye faster and stayed there longer. In addition, subjects gave higher ratings in terms of artistic merit for the renderings that used the same configuration as Rembrandt's work. In brief, this study verifies the impact of texture on guiding viewer's gaze in a painting; such technique can be used to magnify certain areas of a still image as well as a moving sequence.

Findings of the past studies helped us shape our hypotheses and the design of the experiments, which we are going to explain in the next chapter.

3: METHODOLOGY AND EXPERIMENTAL DESIGN

This chapter describes one aspect of the methodology which deals with the hypotheses and experimental design. The chapter begins with an overview of our research and our general hypothesis (section 3.1). Then, we will explain our hypotheses (section 3.2), the designs of the experiments to investigate the hypotheses including the independent and dependent variables, the experiment materials and conditions, and the rationale for these choices (section 3.3). Then, we will describe the parametric approach to painterly rendering and its benefits for facial character sequences (section 3.4). Finally, section 3.5 and 3.6 give an overview of two parameterized computer systems that we exploited for making the facial sequences used in our studies. Additional information on the methodology can be found in Chapter 4: which deals with the user studies.

3.1 Overview

This thesis investigates the promise of computer based painting techniques to enhance emotional expressiveness in games and animations with character scenes. In this regard, we believe the colour palette and texture in a painterly rendered sequence play an important role in the viewer's emotional impression of that sequence. For hundreds of years, artists have used colours to induce a mood, augment a feeling (da Pos & Green-Armytage, 2007) and tell the emotional narrative of their paintings (DiPaola et al., 2010). Also, people intuitively associate colours with feelings. In fact, many studies in psychology have tried to find the link between colours and emotions(Boyatzis & Varghese, 1994; Hevner, 1935; Kaya & Epps, 2004; Terwogt & Hoeksma, 1995; Valdez & Mehrabian, 1994). Although proposing a general model for the association between colours and emotions seems more complicated, we believe such association is more defined in the case of the six basic facial expressions. Texture, which is the textural paint quality and style, is another aspect of a painting that affects people's impression about that painting. As described in section 2.3.3, past studies in art and psychology have examined the affective content of textures and lines (Duke et al., 2003; Halper et al., 2003; Shugrina et al., 2006). Also, a recent study discovered that the textural detail in a painting affects viewer's gaze pattern (DiPaola et al., 2010) (see section 2.3.3 for more details).

Motivated by previous colour and texture studies, our general hypothesis is that *painterly depiction of a basic emotion with the congruent colour and texture properties in a facial character sequence will increase the perceived intensity for that emotion while rendering the same character sequence with the incongruent parameters for that emotion will reduce the intensity perceived for that emotion in the character sequence.*

To investigate these effects in facial character sequences, we programmed specific computer generated painterly rendered facial animations and conducted a series of user studies on these controlled sequences consisting of three pilot studies, two main studies and a final study. Table 1 in section 1.1 provides a chronological overview of the user studies and their objectives. The hypothesis and details of each study is a variation or adjusted version of the general hypothesis, since the focus of the studies and the involved parameters changed as our understanding of the problem area evolved. The following sections describe the main hypothesis and design decisions for each of the studies.

3.2 Hypotheses

As mentioned above, we conducted three pilot studies, two main studies, and a final study. The main difference between the pilot and main studies were in the objectives of the studies and then, the number of participants and the method of recruiting them for the study. The pilot studies were mainly conducted to identify the issues in the experimental design and to help in the design of the main studies. We had between 11-15 subjects for each pilot study, chosen from the graduate students of School of Interactive Arts and Technology (SIAT) and Computer Science (CS) at SFU based on their availability. For the main studies, we had 22-25 participants from the undergraduate students in the department of psychology at University of British Columbia (UBC) who participated for course credit. The complete information on all the studies can be found in chapter 4. Here we will explain the hypotheses for only the main studies.

In all the studies, we examined the facial sequences of four chosen emotions: Anger, Joy, Fear, and Surprise. The focus of the first main study was on the effect of two colour palettes: 1) green-yellow or warm colour palette, and 2) blue or cool colour palette. Thus, the hypothesis for the first main study was as follows:

Hypothesis for the first main study: *A painterly rendered facial character sequence with the yellow-green (warm) colour palette will be perceived as more positive compared to the same sequence painted in the original colour palette. The same facial sequence painted in the blue (cool) colour palette will be considered as more negative compared to the sequence in the two above palettes. Therefore for the positive emotions such as joy and surprise, the depicted sequence with the yellow-green colour palette will increase the perceived intensity of that emotion while the same sequence painted with the blue palette will be perceived less intense. For the negative emotions such as anger and fear, the mentioned colour palettes will have the opposite effect.*

We also expected that subjects will perceive a combined emotion rather than a single emotion, such as perceiving a combination of sadness and fear, or perceive changes in the intensity of the secondary emotions according to the colour palettes.

For the second main study, we introduced a “center of interest” area around the eyes of the 3D face in the emotional character sequence for two reasons: 1) to add variability to the experiment, and 2) to understand how much focused eyes versus nonfocused eyes affect people’s feelings about an emotion. We expected to see the same colour effect as in the hypothesis for the first study. Furthermore, we anticipated that subjects will perceive more intensity in the focused-eye version of anger movies, whose key feature lie in the eye region. Therefore, the hypothesis for second main study was:

Hypothesis for the second main study: *A colour effect similar to the first hypothesis is expected. For anger whose key feature lies in the eye region, subjects will perceive higher intensity in the sequences with focused eyes.*

Based on the results of the second study, we redesigned the palettes and painting parameters for the final study in order to eliminate some of the issues observed in the first two studies. According to da Pos and Green-Armytage's study (2007), we realized that there might be specific colours congruent with each emotion. Therefore, we designed a congruent colour palette for each of the four emotions in our study. In addition, the focus of our study in terms of texture shifted from the "center of interest" area to the "brush characteristics" in the final study. Based on previous affective studies in NPR (Halper et al., 2003; Shugrina et al., 2006), we recognized the texture characteristics as a factor worthy of studying. Therefore, we formed the hypothesis for the final study as follows:

Hypothesis for the final study: *For each of the four emotions examined, the painterly rendered facial sequence with the congruent colour palette increases the perceived intensity of that emotion compared to the perceived intensity for the same facial sequence painted with the original palette. Furthermore, the painterly rendering of the same facial character sequence with the incongruent colour palettes either decreases the perceived intensity for that emotion or does not change it compared to the ratings for the original palette sequence.*

We also expect to see an impact of colour palette on the intensity of secondary and perhaps tertiary emotions. In terms of texture, we did not have any specific hypothesis, and we mainly intended to explore the possible effects of brush properties on the perceived intensity of emotions. The details of texture and brush properties used in the final study can be found in section3.3.2.

3.3 Design of the Studies

In order to test each of our hypotheses, we designed a quantitative study. All experiments have a within-subject design except for the second experiment which uses a mixed design. We chose a mixed design for that experiment to: 1) introduce more variability into the experiment design and avoid subjects from guessing the purpose and variables of the experiment, and 2) prevent issues related to subjects' fatigue because of the high number of movies after adding a new head model to the experiment.

We used the six basic expressions introduced by Paul Ekman as universally recognizable expressions (joy, sadness, anger, disgust, surprise, and fear) as the base for our measurements. Although, Ekman later expanded his emotion list to 15 emotions by adding amusement, contempt, contentment, embarrassment, excitement, guilt, pride in achievement, relief, satisfaction, sensory pleasure, and shame (Dalgleish & Power, 1999), the exact facial configurations for those expressions are not known. In addition, most of the work on virtual/animated agents relies on the first six expressions as the core expressions. Therefore we decided to use the six rather than the 15 expressions as the base for our measurements. As a result, all of the studies have six dependent variables representing the perceived intensity of the six basic expressions. All of the dependent variables were discrete ratio values ranging from zero to six. The default value was zero, which means that the subject did not observe the expression in the movie. Subjects could set the intensity by moving each slider up and down after watching each movie. For analyzing the results, we used the average slider value entered by a subject over three to five repetitions of a movie; therefore, the final six dependent variables in our analysis were continuous ratio values between zero to six. Using sliders poses some limitations on this study, some of which are because we only considered the six basic emotions as the units for the observed emotions. The appropriateness of the computer apparatus for the studies is discussed in section 3.1. Section 5.1 contains a more detailed discussion of the implications of using sliders.

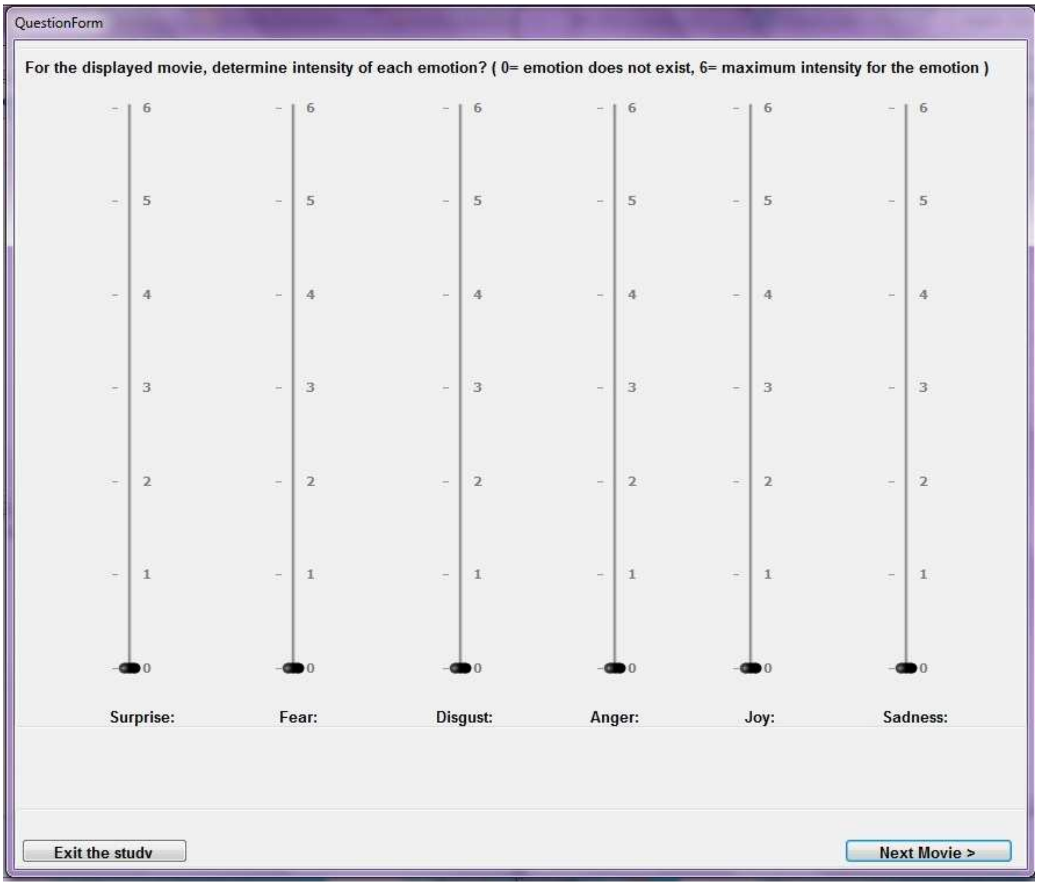

Figure 3- Question form with six sliders

The independent variables of the experiments are expression type, colour palette, and expression intensity. In addition, we had “center of interest” and head model for the second experiment and texture type for the final study. Expression/emotion type in the studies consists of four emotions: anger, joy, fear, and surprise- which are a subset of the Ekman’s six expressions. The first pilot study did not include joy. The colour palettes were different for each study and therefore are described separately in section 3.3.1.3. Depending on the study, expression intensity was two or all three of low, medium, and high intensities. Details on “center of interest” area and texture are described in section 3.3.2. Head models were different depending on the study and are described in more details in chapter 4.

We developed a computer application to capture the subjects’ responses in the study. The program saves the movie name with the chosen slider values for the six expressions in a text file. In addition, we controlled for the experiment conditions such as using same colour/brightness/contrast settings for the two CRT monitors (viewing conditions), giving subjects the same verbal instruction at the beginning of each experiment session, using a quiet experiment room with similar monitors.

The movies for all experiments were short painterly rendered 3D facial character sequences. The head model in the movies were either a 3D pregame test head from a Radical Entertainment (2010) or a 3D head model developed by past iViZLab researchers (“iVizLab - Simon Fraser University,” 2010). Each movie begins with a 3D head model in a neutral position, facing a 45 degree angle on the left of the screen at first which then turns to the viewer and animates up from a rest position to the given facial expression (emotion), stays there for about one second and depending on the study it either stops there or returns back to the neutral expression. We chose this realistic and narrative sequence style so that it appears to be a part of a longer sequence, and as a result brings a sense of story to this short sequence, that can be perceived as a character from a video game or animated movie. The animation sequence were based on years of work on the iFace system which uses parameterized techniques and was validated via several studies(Arya et al., 2009; Arya et al., 2006; Zammitto et al., 2008). Furthermore, non-painterly “base” animation versions of every emotion sequence were shown to participants in all studies as a default baseline.

The choice of colour palette and texture is explained in more detail in the next section.

3.3.1 Colour Palette

The following sections give a brief overview of the major colour concepts such as tonal and colours for portraits, extracted from DiPaola’s work (2007a) on portrait painterly rendering.

3.3.1.1 Tonal

According to DiPaola (2007a), the relative lightness of an object is denoted by the tonal value/tone. Artists usually exploit a ‘tone first approach’ and choose the colour at the stroke level based on a sampled tonal value. This approach helps the artist to achieve the integrity in the painting while using a variety of colours. In general, portrait artists mainly use the following types of tones:

- Body tone (or light) – this tone is used for areas close to the light source or direct light, using warm colours.
- Halftone – this tone is for areas between light and shadow.
- Body shadow – this is the tone for dark areas and the areas away from the light source. Artists usually use cool colours in these areas.
- Other Types are: Cast shadows, Reflections, and Highlights.

We used a painterly rendering system, called "Painterly", for rendering the frames for the movies in different colour palette. The painterly system uses these four tonal values and gets five palette files as input corresponding to: hair, background, clothes, body tone, and shadows.

3.3.1.2 Colour

Colour temperature denotes the relative warmth or coolness of any given colour. One way to determine the appropriate temperature in a given area of painting, is to determine the lights in the scene; a warm light results in cool shadow areas while a cool light leads to warm shadows.

According to the rule of unequal balance, the cool and warm temperatures should be unequal in the painting. Portrait artists usually use warm light as the dominant value. Also, most portraits have a dominant colour. There are a number of colour systems such as RGB, *La*b** (see section 2.3.3 for a brief description of the *La*b** colour system). However, many artists use the Munsell colour notation system with five principal hues: red, yellow, green, blue and purple. These hues are spaced equally around a colour wheel. A more detailed description of this system is available in section 2.3.3. (DiPaola, 2007a)

3.3.1.3 The Colour Palettes for the Studies

We used different colour palettes in different studies. The colour palettes for the first two main studies are demonstrated in Figure 4. The warm (yellow-green) colour palette is mainly comprised of yellow for the face and green for the background. According to the art theories (DiPaola, 2007b), the cool/warm judgment of colours is relative. While the yellow in our palette is considered a warm colour, green is a cool colour compared to yellow and warm compared to blue. As said in section 3.3.1.1, a portrait picture is normally comprised of warm and cool areas. Therefore, we decided to use yellow and green as warm and cool shadows respectively for the warm colour palette.

The cool (blue) colour palette for the first two studies was mainly comprised of blue (for background and parts of the face) and unsaturated pink for skin. In this case, blue is the cool colour and the pink colour is the warm shadow.

Figure 4-Warm and Cool colour palettes

We chose these colour palettes based on art theories about using warm and cool sections in a portrait picture and our intuition about their possible effect on the viewer.

Based on the results of the first two main studies, we decided to redesign the colour palettes according to the past colour studies. Thus, we designed three different colour palettes for the final study. These three colour palettes are based on data from a study by da Pos and Green-Armytage (2007) with two groups of designers as participants. da Pos and Green-Armytage investigated the association between colours and the six basic facial expressions and found an overall consensus among designers in attributing colours to the basic facial expressions. We used the data from their study to design a colour palette congruent with each facial expression. As the provided colours by da Pos and Green-Armytage for surprise and joy were close, we defined one colour palette congruent with both of them: the yellow-orange/warm-light colour palette (Figure 5). The blue-gray/cool-light and later the pale colour palette (Figure 5) were considered congruent with fear and the red-black/warm-dark colour palette was designed to boost the effect of anger (Figure 5). We only applied the colour palette to the face, keeping the gray background colour unchanged. The paper by da Pos and Green-Armytage (2007) provided charts based on the average of chosen colours in the *La*b** system. The average values provided in the paper and the average colours of faces after applying each of our colour palettes are provided inTable 2.

Figure 5- Four colour palettes for the final study

Table 2-La*b* values for the colour palettes in da Pos and Green-Armytage's paper and our colour palettes

	L	a	b
Average colours provided in the paper			
Anger	30	22	10

Fear	50	8	10
Surprise	60	15	30
Joy	60	17	42
Average colours of faces after applying the designed palettes			
Anger	36	40	41
Fear	53	7	12
Surprise/Joy	64	23	47

3.3.2 Texture Quality

In terms the texture quality, we were mainly concerned with: 1) "center of interest" and 2) brush stoke properties.

A "center of interest" area in a painting is a detailed region created by specific edge properties and smaller brush strokes compared to the strokes for the rest of the painting. Based on past studies, such an area in a portrait, e.g. an intense eye area, can attract the viewer's gaze and convey the message intended by the portrait artist (DiPaola et al., 2010). Thus, for the second study, we decided to explore the impact of a focused region around the eyes on the viewers' perception of the displayed emotion in a facial character sequence. For an example of focused eye vs. nonfocused eye see Figure 6, Figure 7.

Figure 6-Nonfocused eye on the male head

Figure 7-Focused eye on the male head

In addition, the texture of a painting significantly depends on the properties of the brush for that painting such as shape and size of the brush. We created two texture types by changing the size and curvature properties of the brush. A larger brush size with higher curvature value resulted in a "blurry" texture while a smaller brush with less curvature generated a "jaggy" effect. An example of the two brush types is shown in Figure 8. The complete configuration for the two brushes can be found in the painterly configuration files in the accompanied CD-ROM.

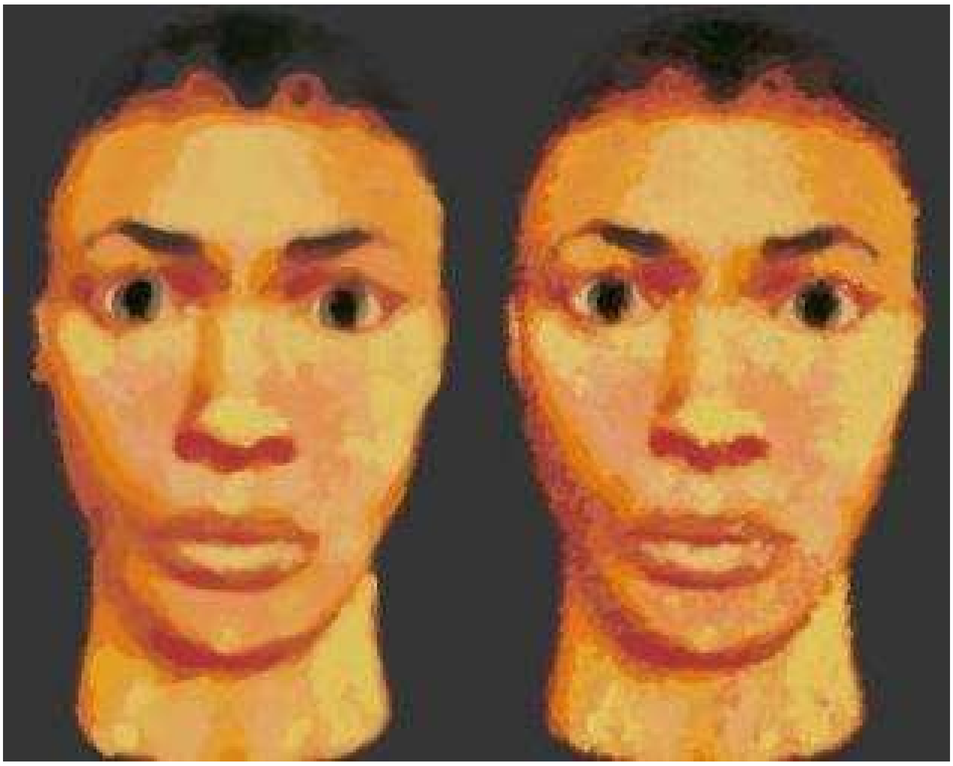

Figure 8-Blurry and jaggy brush styles

In the next section, we will describe a parametric approach to painterly rendering for facial sequences and its benefits for more appealing results.

3.4 Parametric Approach and Its Benefits for This Technique

Since our proposed method adds expressiveness to a sequence by changing the visual style, its effectiveness highly depends on the ability of the depiction system to produce appropriate visual effects in the right places in the frames of the sequence such as using dark red colours for the frames displaying anger. Parametric authoring tools both in the animation and depiction side help in better control over the painting process and thus more appealing results.

Semantic or content-based NPR techniques empower existing algorithmic approaches by providing additional information about the content of the input image. Santella and DeCarlo (2002, 2004) used data from an eye tracker to determine the regions of higher saliency in an image in order to paint those regions with more details compared to the other regions of the input image. O'Regan and Kokaram (2009) used skin and edge detection techniques to recognize people's head within a video sequence and set the appropriate painting ammeters for those areas.

Similarly, having knowledge of different parts of the face is very useful in the process of portrait painting, as it allows the painting system to adjust painting parameters based on the characteristics of the facial feature and the desired final effect. Thus, tying the depiction system to a parametric facial animation system seems a promising approach. Facial sequences can benefit from the well-structured standards for face features and facial movements, and thus, these sequences have a great potential for being painted sophisticatedly compared to the sequences of other contents such as landscapes etc. We will describe the available facial standards in the following section.

3.4.1 Face Parameters and Facial Animation Standards

There are two well-known standards for faces: the MPEG-4 standard for faces and Ekman's Facial Action Coding System (FACS). FACS was developed by Paul Ekman in the field of psychology to study the human face and its emotions. FACS is based on the minimum perceptible actions that a human face can perform and benefits from underlying face principles. It is composed of 32 Action Units (AUs). Each AU denotes the smallest perceptible facial movement. Nevertheless, FACS parameters are not completely independent; for example, some action units cannot be active together while some others usually move together. Moreover, most AUs are symmetric but some facial expressions are not. Appendix B includes a list of Action Units. As FACS was developed based on the movements of facial muscles, it is commonly used with simulation-based approaches for facial animation such as pseudo-muscle and muscle-based approaches. One advantage of the FACS system is that the ccombinations of Action Units for the six basic expressions are known (see Appendix B)

A parameterized approach to the face and its animation was first introduced to the computer graphics community by Fred Parke. He realized that many areas such as surgical/dental procedures and data compression could benefit from having a "complete" set of parameters for faces. In this regard, a set of parameters is considered complete if all faces can be uniquely defined by choosing appropriate values for the parameters. He developed a set of parameters based on the Facial Action Coding System (FACS): 1) conformation parameters for face structure, and 2) expression parameters for facial animation. Some of the conformation parameters are as follows:

- neck length and shape
- chin, forehead, cheek, and cheekbone shape

- eyelid, eyeball, and iris size and the position and separation of the eyes
- jaw width
- nose length and the width of the bridge and end of the nose
- Chin and forehead scale and the scale of the mouth-to-eyes portion of the face vis-a'-vis the rest of the face.

Another standard commonly used by facial animation systems is the MPEG4 standard for face animation. The MPEG4 standard includes Facial Definition Parameters (FDPs) and Facial Animation Parameters (FAPs). FDP is a set of 88 parameters used for defining the position and size of the face features. It could also contain information about the texture of the face. Figure 9 shows the FDPs defined in MPEG4. FAP, which is the set of parameters for facial animation, is more fine-grained than FACS. It is mostly designed for engineering applications such as compression and teleconferencing. The FAP set includes 68 parameters, with 66 low-level parameters related to the movements of lips, jaw, eyes, mouth, cheek, nose etc., and two high-level parameters for visemes and expressions. Visemes are the visual representations of mouth while pronouncing phonemes. Expression parameters in MPEG4 standard consist of Ekman's six basic expressions: joy, sadness, anger, fear, disgust and surprise. The standard also includes Face Animation Table (FAT) which is useful for translating the feature movements to the low level vertex movements in the underlying mesh. FAP Interpolation Table (FIT) allows interpolation for the FAPs. FIT allows the reconstruction/replay of a facial animation sequence from a small set of FAP values. The rest of FAP values can be interpolated from that small set based on the FIT table.

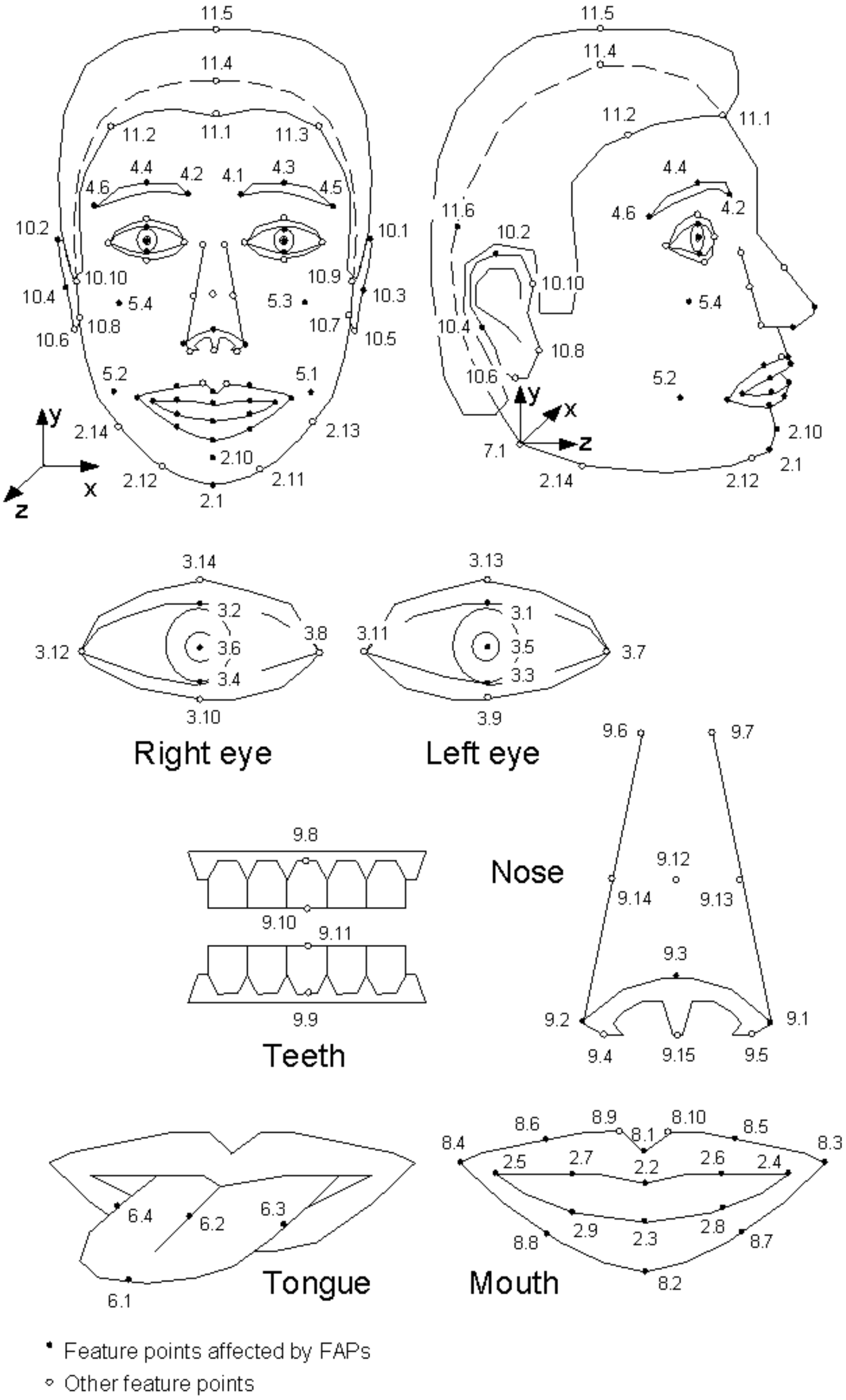

Figure 9-MPEG4 Face Definition Parameters (FDP)

A number of applications have been developed based on the above standards. rFace (DiPaola, 2002b, 2002a) and iFace(DiPaola & Arya, 2004a, 2005) are two proprietary software systems developed for face research. rFace is based on the parameterized face space defined by Fred Parke(2006) and completed by Steve DiPaola (2002b, 2002a). The parameters for face creation and animation in rFace are arranged in three groups: 1) eye, 2) mouth, and 3) face. The parameters are unitized vectors that control the low-level movement of a specific part of the face. These parameters are abstracted in a way that allows combination, addition and subtraction operations on them to define higher level parameters/controls. In this way, one can build up a hierarchical library of behaviours, expressions and character types. In addition, the rFace system is able to analyze, in real-time, the inputted voice audio for lip-syncing and generating the appropriate gestures and movements based on the defined personality for the character.

iFace is a more recent animation tool developed by iVizLab group (“iVizLab - Simon Fraser University,” 2010) for specialized face animation and research and we will describe it in more detail in the following section. Most of the information in the following section is based on DiPaola and Arya’s research (2004a, 2005).

3.5 iFace As a Parameterized Facial Animation Authoring Tool

DiPaola and Arya (2004a, 2005) developed the IFACE framework as a set of .NET components written with C#. Interactive Face Animation Comprehensive Environment (iFace) is a general-purpose software framework that provides programming interfaces and authoring tools for defining a face object, its behaviours, and animating it in static or interactive situations. Four spaces of geometry, mood, personality, and knowledge in the framework, cover the appearance and the behaviour of a face object.

Geometry: this parameter space is concerned with the physical appearance and movements of facial points. In iFace, face structure is grouped into three levels of increasing abstraction: vertices, facial features/parameters, and facial regions. iFace allows the user to manipulate the face on all three levels: vertex level, facial feature level and region level. Higher levels in the hierarchy have access to the lower levels internally. This architecture helps in hiding the details from users and programmers.

Knowledge: the knowledge space is concerned with behavioural rules, stimulus-response association, and the required actions. iFace uses an XML-based language called FML to support the knowledge space. FML is specifically designed for face animation. An FML file can incorporate a sequence of actions by a head model or a set of parallel and event-based actions. IFACE can play this sequence of action.

Mood: This space is concerned with short-term emotions of a character and affects how an action is animated.

Personality (long-term individual characteristics): This space deals with the long-term individual characteristics and is mainly based on the facial cues associated with a given personality type. The association between facial cues and personality types is derived from the user studies (Arya et al., 2009; Arya et al., 2006). The personality cues could be expressions, 3D head movements, nodding, raising/lowering/squeezing eyebrows, gaze shift, and/or blinking. As an example, a recent study with iFace suggested that people associated dynamic facial actions such as head tilting and gaze aversion with the dominance dimension, while the facial expressions of contempt and smiling affected the subjects' ratings along the affiliation dimension. In addition, the characters with the higher frequency and intensity of head actions were perceived as being more socially dominant.

These four spaces provide the underlying structure and functionalities for making expressive facial sequences.We believe that incorporating multiple visual styles into iFace adds to the current features of iFace for making expressive character sequences. In addition, since iFace uses MPEG-4 standard for faces, the generated facial sequences include information about face features. This feature of iFace makes it perfect for integration with a depiction system capable of applying different effects to different regions. The result of such integration is more sophistication in the painting process, which leads to better visual results.

3.5.1 iFaceStudio

iFaceStudio is an application developed using iFace libraries. It is composed of four main parts: iFace3D, iFaceStudio Imager, FaceControls, and Keyframe Editor.

FACE3D: This window displays the 3D head, allows the user to rotate the head, change its distance, and display a wireframe view of the head.

FaceImager: This window shows the texture of the face. The local controls are for zooming, enabling pan mode (moving the image by dragging the mouse), and showing the defined regions on the 3D face.

FaceControls: This is the main window for controlling the iFaceStudio Application. It has the following subcomponents (see Table 3):

Table 3-Subcomponents of FaceControls

Component	Functionality
iFace	This tab contains general controls for selecting the personality for the 3D head, opening and displaying an animation file, recording audio file, and capturing/saving all frames of an animation
Geometry	This tab gives access to component-level parameters and has features for modifying existing parameters or adding new ones.
MPEG4	This tab is for MPEG-4 FDPs and FAPs . Each parameter has group, param, and subparam values. For example the expression Joy is a FAP in group 1 with param value of 2 (expressions) and subparam value of 1. The program lets the user the define FDP and FAP on the underlying head model. Group-1 FAPs are defined as a combination of others and could be defined in this tab.
3D Setup	This tab is for 3D settings, loading a new head model and defining or modifying the regions.
Imager Setup	This tab is for 2D settings. This includes the base image and options for defining or modifying the regions. The info is saved in an .img file.
View/Tools	These are some general controls for viewing and special tools for setting the directional and ambient lights.

The Keyframe Editor component is accessible from View/Tools and is a tool for making keyframed facial sequences, which we will describe below in more detail.

3.5.2 Keyframe Editor

The Keyframe Editor is an integrated part of iFaceStudio; the editor is based on the MPEG-4 standard for faces and enables the user to make facial sequences rapidly. The user can create a new .kyf file, insert/remove key frames, add parameters to the file and set their values. The editor arranges and displays the key frames and the parameter values to the user in a tabular format. Each parameter has a slider for changing its value. iFace3D window gives the user real-time feedback on the result of changing the value of a parameter. In MPEG-4 standard, the face parameters are arranged in 11 groups corresponding to the facial regions. The same grouping was used in the Keyframe Editor. However, for the animator's convenience, the Keyframe Editor uses meaningful names for groups instead of numbers provided by the MPEG-4 standard (e.g. mouth instead of group 3, and eyes for group 4). The editor supports undo/redo for all user actions.

The Keyframe editor benefits from a timeline that displays key frames and enables the animator to move through the animation file for adjustments and tuning the sequence. Finally, the animator can save the keyframe file and reopen it later.

The keyframe editor for iFace was specifically built by the author to extend iFace to the level of animated sequence control needed for the research studies in this thesis. In addition the author also scripted the animation using this keyframe editor.

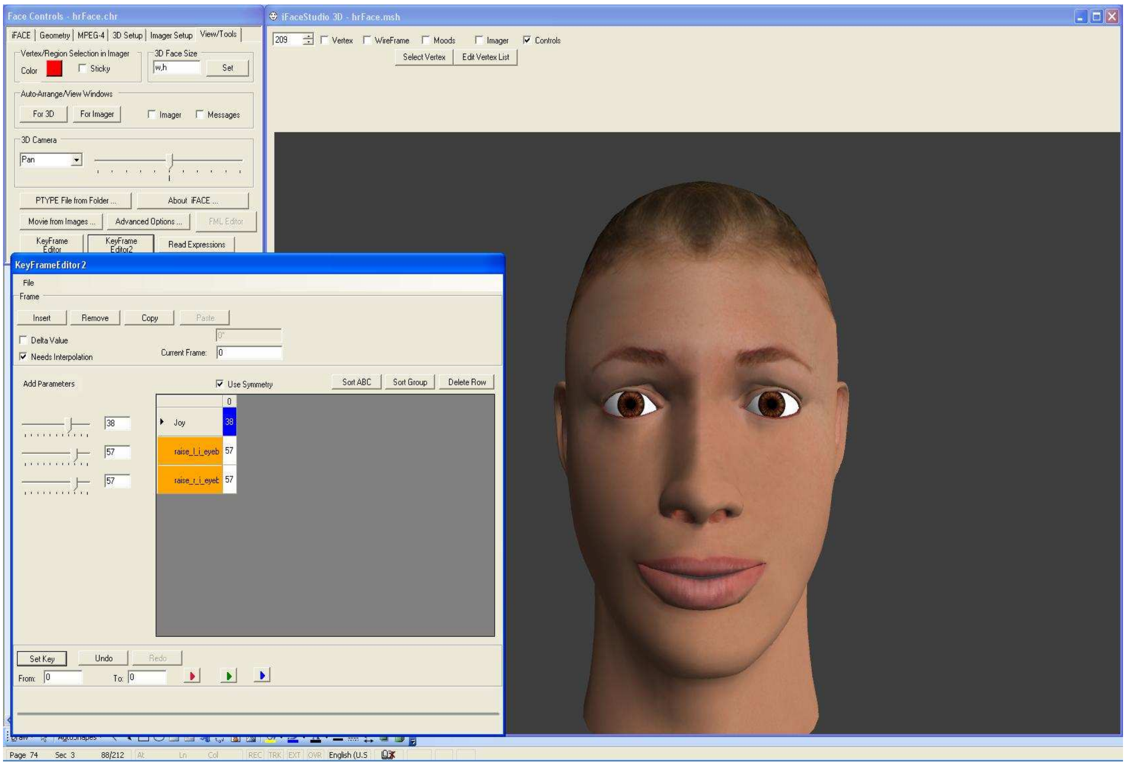

Figure 10-Screen capture of iFace and the keyframe editor

For an NPR system to be flexible and to generate a wide variety of outputs/styles, it should provide the user with a set of controls. In such a system, the user or algorithm can adjust the parameters based on the input image and the desired effect/style. We used the “Painterly” system to make painted sequences for our studies; it is a parameterized NPR tool for making portrait paintings out of the input head shots. Next section contains more description on “Painterly” and is mainly based on DiPaola’s research (DiPaola, 2007a, 2007b) on the “Painterly” system.

3.6 Painterly As a Parameterized Semantic Depiction System

The "Painterly" system is a parameterized NPR toolkit, developed for portraiture paintings and thus takes advantage of portrait and facial knowledge in the NPR process. The program has been developed based on the collected qualitative data from art books and interviews with portrait painters tied with facial and cognitive knowledge a human painter leans on when creating a portrait. The qualitative data about how portrait artists achieve the final painting was then translated into a parametric model and incorporated into the painting algorithm (see Figure 11). In this regard, the "Painterly" system is different from most other NPR techniques, which solely rely on image processing techniques such as edge detection, and image segmentation. Painterly was originally developed for a two-fold interdisciplinary goal. First was to explore the space of all possible combinations of painting parameters and provide a wider range of results compared to the current techniques. The second goal was to provide a tool for exploring interdisciplinary questions about art and human perception. This research generally fits into the second goal.

In practise, low level parameters in the "Painterly" fall into functional types: 1) parameter constants such as brush size, 2) method parameters such as OriginalColourPalette which uses a method that uses the colour of the input image for each brush stroke, and 3) process method parameters which guide the process flow of the other parameter types (i.e., do this before this)

The "Painterly" system can differentiate and recognize areas of portrait scene thereby approximating the cognitive knowledge a human painter has and in practice differentiates background, hair, clothes, face and eyes which are the most important parts of a portrait picture. In addition, specific regions of the input image can be determined in a matte file to be painted with the desired parameter settings. This capability enables a technical user to produce sophisticated paintings.

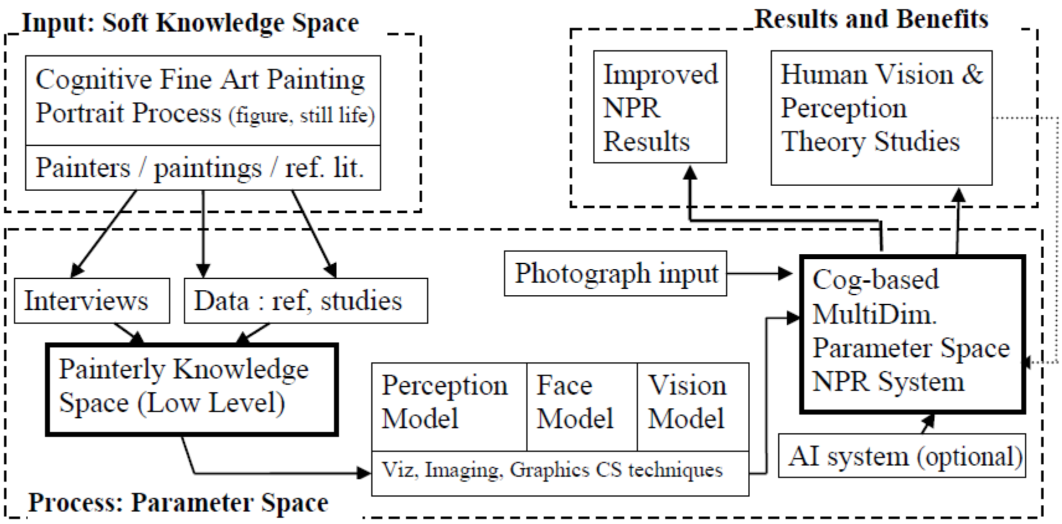

Figure 11- The process chart for making the Painterly system (from (DiPaola, 2009))

3.6.1 Specifications of the Painterly System

The “Painterly” system receives a set of painting parameters such as brush size and colour palette in an XML format, together with the name of the input image and a number of map/matte files depending on the desired output, and renders the input image in an oil-painting style using the 3D OpenGL standard. The input XML file contains the initial conditions, painting parameters, number of passes and the algorithms to use. Algorithms or techniques are higher level cognitive painterly techniques that mimic a specific artist’s process. Users can specify the regions of the input image including the background, hair, clothes, and shadows in a map file to be painted with different colour palettes or styles. The “Painterly” system also accepts matte files. A matte file is used to denote those parts of the input image which can be treated differently for instance painted with a special more detailed pass. All of the parameters and the configuration attributes are pixel resolution independent, which allows all global and local scaling to be rescaled by a few scale parameters.

The system works in multiple passes similar to algorithms by Haeberli and Hertzmann to simulate how human painters work. Using larger brush strokes for the first passes results in a rough sketch of the scene, and smaller strokes in the following passes achieve the desired level of detail. This algorithm simulates how painters first put large tonal masses and progressively add more details over the previous layer. In terms of the colour palette, the system provides several options such as using the colours from the original image, another reference image, or a set of colours placed in an image file as the colour palette. The system can also output a rendered XML based brush stroke list file with full details of stroke properties, stroke positions and curvature nodes including temporal and comment data.

We used the “Painterly” system for rendering the frames from the iFace based facial character sequences, which were in the computer graphics style, into the painted frames with the desired colour palettes and texture styles.

4: USER STUDIES

In this chapter, we will explain the conducted pilot and user studies to examine the hypothesized effect of the colour palettes and texture styles chosen. In total, three pilot studies and three main studies were conducted. The issues and results raised by the three pilot studies and the first two main studies lead to the design of the final study with a more rigorous study setup both in terms of emotion animation over time and colour specifics. Section4.1 describes the common characteristics of all of the studies. In sections 4.2-4.6, we explain the preliminary pilot and main studies which lead to the final study described in section 4.7.

4.1 Overview of the Experiments

We tested our hypothesis by conducting a number of user studies, more specifically three pilot studies and three main studies. The first pilot study was designed to ensure the sensitivity of subjects to the three chosen intensity levels for each expression. The second pilot study was conducted to investigate the perceptual differences between the computer graphics (CG) version and the painted movies in the original colour palette. Next, the first and second main studies examined the effect of colour palette. In the second main study, we added a “center of interest” region, mainly to introduce more variability into the study and prevent subjects from guessing the purpose of the study. The third pilot study was conducted on still images to test the new colour palettes designed after the second main study. Lastly, in the final study, we used the new colour palettes on dynamic facial character sequences along with texture quality as a new factor.

Because all of those user studies have similar underlying structure, we will explain the common elements in all of them in the following sections.

4.1.1 Head Model

The head model in our experiments refers to the 3D model that expresses one of the six emotions in the movie sequences. We used the iFace program as the source for our head models and facial animation files. Each head consists of a 3D mesh and a JPEG texture file; the head can be modified and moved using MPEG4 parameters. The head model for the two pilot studies and the first main study is a pregame test male head model for the "Scarface" game by Radical Entertainment, which is a local game company ("Radical Entertainment," 2010). The second head model is a Caucasian female created by previous iFace researchers. Figure 12 shows the screen shots of the two head models.

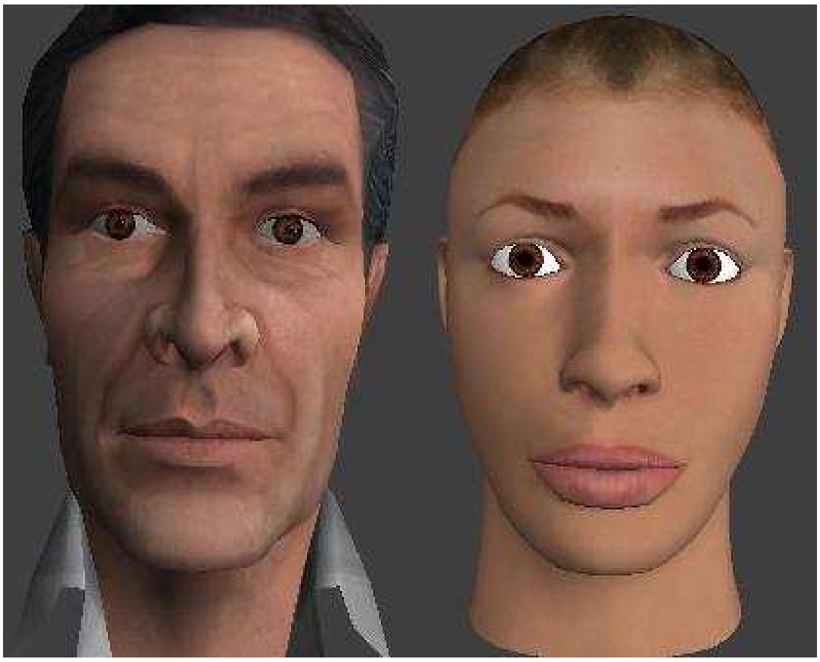

Figure 12-Male and female head models

4.1.2 Apparatus

The apparatus for our studies is a .NET windows application written in C#. It displays a random sequence of movies to the participants and saves their responses in a text file. At the beginning of a study session, a windows form asks the researcher to enter the number of repetitions for each movie, and the subject's initials. After that, the program generates a random ordering of the experiment movies and displays the first movie in the sequence. After watching each movie, the participant either automatically or by his/her choice is lead to the response form with six sliders representing the six basic expressions. The participant can choose the intensity for each of the six basic expressions perceived in that movie. The program saves the choices made by the participant for each expression in a text file. After the second main study, the program saves the click data that is the time for each of the participant's actions including changing the values of sliders and finalizing the choices. The reason for capturing the click data was to recognize any abnormalities in the data and also to find any outliers. The apparatus was developed based on the requirements of the study and was designed to be simple for users and do not induce any bias. Some small changes were made to the apparatus during the course of user studies in order to improve its functionalities. For example, adding the ability to go back and watch the movie again in the final study or saving the click time data after the first main study.

4.1.3 Movies

We created all of the movie sequences out of the frames rendered by a 3D facial animation tool (iFace) with a rate of 24 frames per second. Then every third frame of the sequence was painted using the "Painterly" program. We will describe the parameters for making the painted frames in section 4.1.4. Finally, we made each movie by importing the painted frames into the Adobe Premiere CS3 where we added cross dissolves and reducing the speed to 33% which resulted in 24 fps movies. These last two techniques help make the movies less jumping, increasing their frame to frame coherence. We exported all of the movies with 872*670 pixels resolution in QuickTime format, without the audio channel and with Sorenson 3 as the compression type. The sample and experiment movies could be found in the accompanied CD-ROM.

4.1.4 Painterly Parameters for Movies

We used our “Painterly” system to make the painted versions of the CG frames. “Painterly” uses a source input image, other input information such as regional face information in the matte files, colour palettes for those regions and a XML script file that contains the set of parameters and algorithms to use on that source image and output a final painterly rendering portrait. We used batch files to run “Painterly” on the sequences of frames generated from iFace. In this section, we describe the set of parameters that we used for painting the frames of the movies.

The “Painterly” program works with passes to simulate the way artists build up a painting. The painting technique and brush properties are configurable for each pass. The number of passes and the parameters for each pass is specified the XML script file. As in art, the first passes use larger brush strokes to make a rough sketch of the input image. The following passes add the details and the desired fine effects for the final output. We used three passes for painting the frames of our movies.

We mainly used two types of colour palettes for our studies: OriginalColourPalette and PortraitPalette. The OriginalColourPalette uses the colour of the input photograph at each point as the colour of the brush stroke. In contrast, the PortraitPalette requires five child colour palettes to use for specific areas in an input image. These areas are background, clothes, hair, body tone and shadows and are marked in a map file with pure colours: blue is used for extracting the background area, green for the clothes, black for the hair, white for the body tone, and red for the shadows. A palette file for each of these five areas is an image file containing all the colours to be used in that area. A child palette type for each area determines the association between the colours of the input image area and the colours in the palette file. We used the PortraitPalette in painting the frames for the third pilot study and the final study since this sophisticated regional colour technique mimics how artists work and was used for the earlier studies by DiPaola et al. (2010) that our studies are based on.

In terms of the painting technique, we used SubBlobAlgorithm for all passes. This technique is a variation of BlobAlgorithm, which works in two passes; the first pass places blobs at regular intervals while the second pass paints the blobs. The initial direction of the strokes in each blob is along the average gradient of the blob. In this algorithm, subblobs hierarchically retain information about the blobs generated in the previous passes and create child blobs of lighter or darker value within their parents. The blob and subblob algorithms approximate how humans detect shapes, and apply brush in those shapes, rather than cognitively work on each brush stroke individually.

Brush is another configurable parameter set in the “Painterly” program. We mainly used two brush types: GLCircularBrush , and GLTextureBrush.

GLCircularBrush was the brush type for all the studies except for the third pilot study. This brush drags a circle along the stroke path. We used three passes of rendering, decreasing the value for the brush size: 0.1, 0.01, and 0.0043 (i.e. a size of .1 would be 10% the size of the whole canvas). In order to add a “center of interest” or focused area around the eyes in the second main study, we used a matte file to mark the eye region and a smaller brush size for painting that region in the final pass compared to the brush size for the nonfocused movies.

For the third pilot study, we used the GLTextureBrush. This brush renders the strokes by dragging the provided alpha texture file over the stroke path which given a more textured brush stroke look compared to the previous technique. While this more painterly, the output images for the third pilot study had some artefacts/noises in the background because of using this brush type. Nevertheless, we conducted the pilot study on the generated images with this brush because of the time constraints. For the final study, we used the GLCircularBrush instead of this brush. Another advantage of GLCircularBrush was that we could better configure its curvature and size to get two different brush styles for the final study: jaggy and blurry.

4.1.5 Procedure for the Study

During a session of the study, first, the investigator provided the participant with a brief explanatory description of what he/she is going to do in the study. The investigator showed the sample movies displaying the extreme intensity of the facial expressions to the participant, stating the title and intensity of that facial expression (e.g. “this movie displays fear with extreme intensity”). The participant could watch these sample movies as many times as he/she wanted. Then, the investigator ran the apparatus. After entering the number of repetitions for each movie, the investigator explained the interface of the apparatus to the participant and mentioned that the following movies could display just a single expression or a combination of facial expressions. After watching the first movie, the investigator explained the measuring scale used on the response form with six showing the highest intensity and zero indicating the absence of that expression in the movie. Also, the investigator explained that participant could move more than one slider based on the observed combination of expressions. There was no time pressure on the participant and he/she was left alone to complete the study. The participant was allowed to ask questions but we did not help them with choosing the values for the sliders.

4.1.6 Procedure for Analyzing the Results

In order to analyze the results, the repeated measure ANOVA was calculated on the average response given by each participant on the 3-5 repetitions of each movie. All of the factors were within-subject. The average rating on 3-5 repetitions of each movie is continuous and ratio and has a normal distribution for the subjects.

The subjects of the main studies were from students in University of British Columbia (UBC), and mainly from undergraduate students in the department of psychology who participated in the study for course credit. These studies were conducted in the UBC Vision Lab. For the pilot studies, graduate students from Computer Science and School of Interactive Arts and Technology (SIAT) of Simon Fraser University (SFU) were the subjects of the study. These studies were conducted in the SIAT's research labs. The selection for pilot studies was based on the availability of the subjects.

We analyzed the distribution of residuals for each study separately to ensure that the assumption of normality was met. The assumption of equality of the variances was also tested for each study. The tables for these analyses are included in Appendix A.

4.2 First Pilot Study

This study was designed to investigate whether subjects are sensitive to three chosen intensity levels. Participants chose the type and intensity perceived for each of Ekman's six basic expressions in the displayed movies.

4.2.1 Method

Participants: 13 graduate students (9 female, 4 male) participated in a 15 minutes user study.

Apparatus: the order of emotion sliders on the response form was different from the rest of the studies; the order from left to right was anger, fear, surprise, joy, sadness, and disgust.

Movies: each participant watched nine movies with five repetitions, resulting in 45 movies. The nine movies consisted of the low, medium and high intensity versions of anger, fear, and surprise (anger_low, anger_medium, anger_high, fear_low etc.) each repeated for five times. The sample movies were the three high intensity versions of anger, fear and surprise. In each movie, a 3D face animates from a neutral position to one of these three expressions, and after remaining on the full expression for about one second, the face animates back to the neutral position. The duration of each movie was 3:13 seconds. The full expression was from 1:50 to 2:50 seconds. We used a 22” LCD screen with a resolution of 1024*768 and 32 bits per pixel colour scheme. The head model for the sample movies and the experiment movies was the Radical test head model described in section 4.1.1.

4.2.2 Results and Discussion

The study examined the sensitivity of subjects to the three intensity levels chosen.

Mean and standard deviation values for the responses to each movie indicate that the subjects are adequately sensitive to the changes in the intensity for all the expressions. The only exception was the fear expression, for which the low version was confused with surprise.

After analyzing the responses, we realized that two of the subjects had used the sliders slightly less than the others. Therefore, we removed their responses as outliers. Table 4 shows the mean and the standard deviation of the ratings by each user. Figure 13 shows the mean graph.

Table 4- Mean and standard deviation of the ratings by each user

	Count	Mean	Std. Dev.	Std. Error
User1-0	135	1.237	1.763	.152
User1-1	135	1.148	1.814	.156
User1-10	135	.511	.897	.077
User1-11	135	1.067	1.667	.143
User1-12	135	1.348	2.053	.177
User1-2	135	1.178	1.954	.168
User1-3	135	1.748	2.143	.184
User1-4	135	1.800	1.900	.164
User1-5	135	1.356	2.096	.180
User1-6	135	1.296	2.037	.175
User1-7	135	1.644	2.294	.197
User1-8	135	1.296	1.932	.166
User1-9	135	.748	1.176	.101

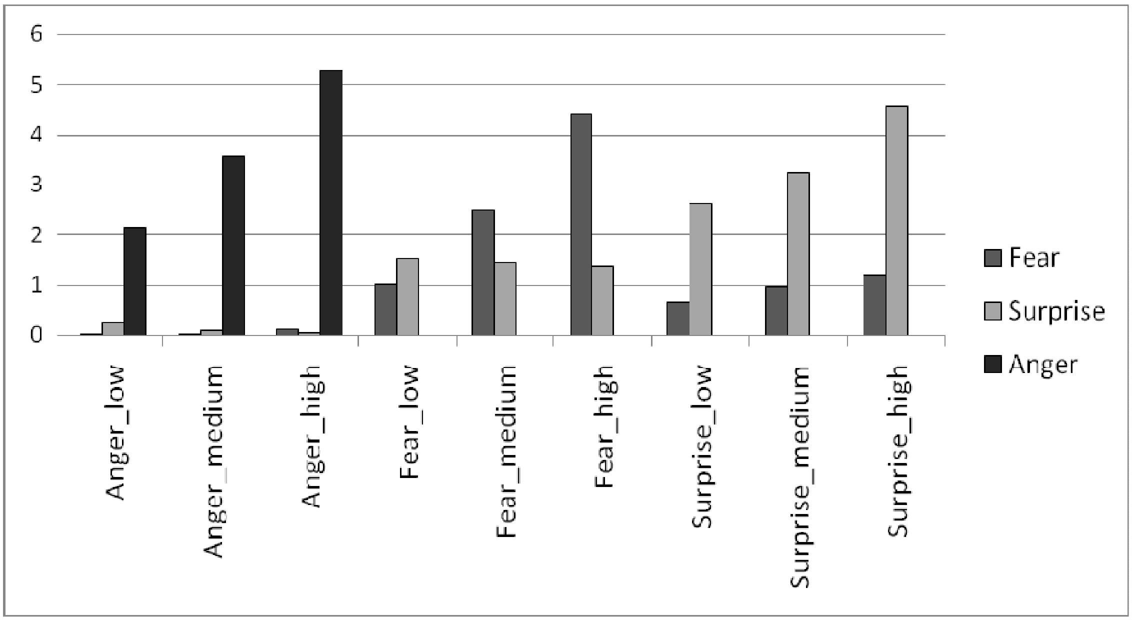

Figure 13-Mean ratings for the low, medium and high intensity movies

A number of points are noticeable in this graph:

1. The anger movies demonstrate the intensity effect and other emotions were not perceived to have the anger mixed in.

2. Both the fear and surprise movies exhibit the intensity effect for fear scores.

3. Only the surprise movies demonstrate the intensity effect for surprise scores; there appears to be a constant level of surprise in fear movies regardless of the intensity.

In addition, the test of repeated measure (within subject) ANOVA was calculated on the average responses over the five repetitions of each movie with the intensity and expression type as two factors. Result of the test indicated the main effect of intensity for the three expressions chosen. Table A 2contains the results of the ANOVA test.

4.3 Second Pilot Study

The purpose of this study was to investigate whether the users' perception of the painted movies in the original palette significantly differs from the CG version of the movies. The results were used to choose an appropriate design for the first study. The only differences between this study and the first pilot study were:

1. The joy expression was added to the set of movies

2. Eliminating the high intensity movies, we only used the medium and low intensity movies for this study. The large number of conditions in the experiment was the reason for this choice. Also we knew from the first pilot study that people are sensitive to the different intensity levels.

3. We rearranged the sliders in the question form based on the order that the corresponding emotion appears in Ekman's book (Ekman & Friesen, 2003). In the first study, the order of the sliders could induce bias, since the sliders for all the three examined expressions were on the left side of the response form.
4. The painted movies in the original colour palette were added to the set of movies for this experiment (see Figure 14).
5. The number of repetitions for each movie was four rather than five in the first pilot study.
6. We showed the extreme intensity of **all the six** basic expressions to each of the participants at the beginning of the experiment.

Figure 14- CG and painterly rendered frame in the original colour palette

4.3.1 Method

Participants: 14 Graduate students (6 female, 8 male) participated in a 15 minutes user study.

Apparatus: The order of sliders for this study was joy, sadness, anger, disgust, surprise and fear.

Movies: 16 movies were shown to each participant with four repetitions, resulting in 64 movies. The 16 movies consisted of the low and medium intensities of the fear, surprise, anger, and joy emotions in two different styles, CG and painted with original palette, and each movie repeated for four times (2*4*2*4=64). For making the painted movies, the “Painterly” program rendered the CG frames from iFace using the OriginalColourPalette. The length, frame rate and the facial sequence of the movies were the same as the previous pilot study. The head model for this set of movies was the Sosa head model.

Procedure: The same procedure as the first pilot study was used in this study. However, at the beginning of the study, the CG movies for the highest intensity of **all the six** basic expressions were shown to the participants.

4.3.2 Results and Discussion

The purpose of this study was to discover the possible differences perceived between the painted movies in the original palette and the CG version of the movies.

Figure 15 displays the mean ratings for all of the movies. According to the graph, the effect of the rendering style (CG vs. painted) was negligible. This means that the computer graphic version and the painted version in original colour palette were not perceived differently in terms of the type and intensity of the expressions by the participants. Only the fear and surprise movies had noticeable secondary ratings of surprise and fear respectively (Figure 16, Figure 17).

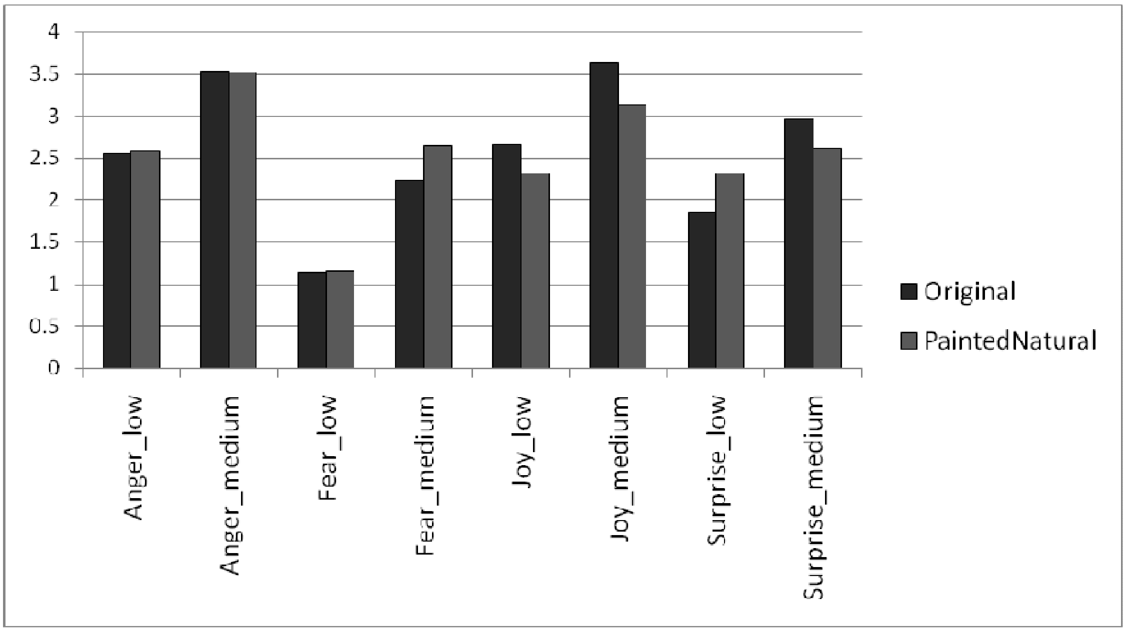

Figure 15-Ratings for the CG (Original) and the painted with original colour palette (PaintedNatural) movies

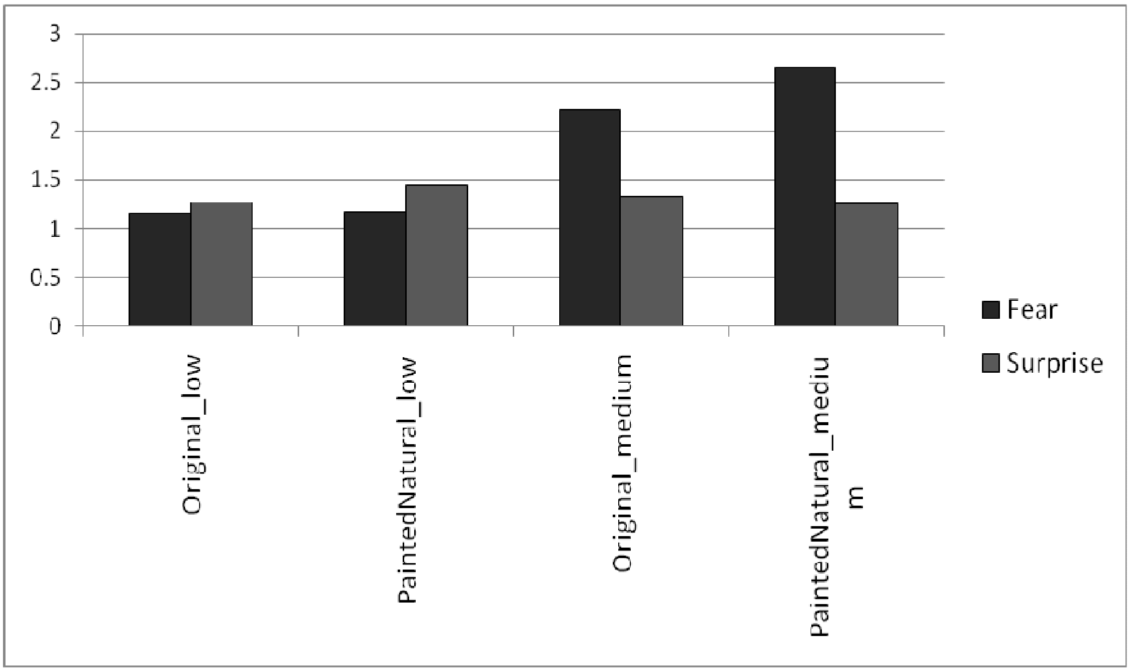

Figure 16-Fear and surprise ratings for the fear movies

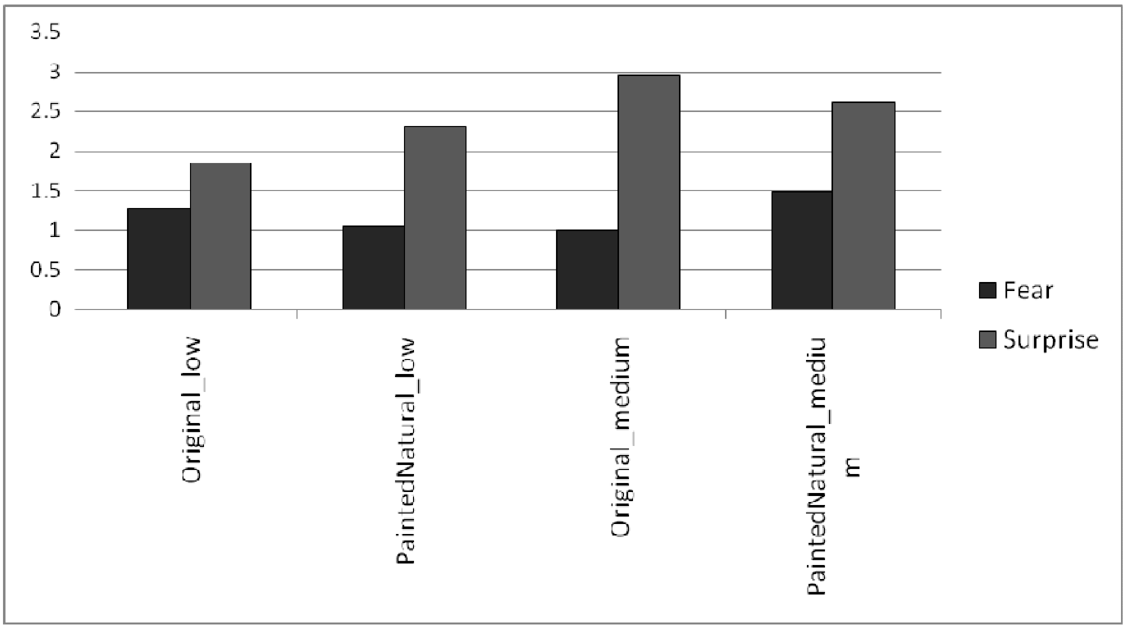

Figure 17- Fear and surprise ratings for the surprise movies

In addition, the mean of slider usage for each participant did not indicate any outliers Table A 5. The test of repeated measure (within subject) ANOVA did not show any significant effect of the rendering style (see appendix A for the results of ANOVA test).

Based on these results, for the first main study we did not extract the rendering style (painted vs. CG) as a separate factor, instead we used four different styles in the first main study: CG, paintednatural, warmpainted, and coolpainted.

4.4 First Main Study

This study was conducted to explore the effect of the warm and cool palette movies on the users' perceptions of the facial expressions in an animated character sequence.

The only differences compared to the second pilot study were:

1. Two colour palettes were added (coolpainted and warmpainted) (see Figure 18)
2. The participants responded to each movie five times.
3. Again we showed the extreme intensity version of **all the six** basic expressions to each participant at the beginning of the experiment.

Figure 18- Four colour palettes for the first main study

4.4.1 Method

Participants: 23 Undergraduate students (16 female, 7 male) participated in a 30 minutes user study for course credit. They had the option to take a five-minute break in the middle of the study.

Movies: 32 movies were shown to each participant in five repetitions, resulting in a total of 160 movies. The 32 movies were the low and medium intensities of the four emotions (fear, surprise, anger, joy) in the four different movie styles (CG, paintednatural, coolpainted, and warmpainted), with five repetitions (2*4*4*5=160). We used Adobe Photoshop CS3 on the paintednatural frames to create the coolpainted and warmpainted versions of each frame, which we then used for making the coolpainted and warmpainted movies. The length, frame rate, and the facial sequence of the movies were the same as the previous pilot study.

Procedure: The study was conducted at the UBC Vision Lab on two Samsung 14.5" CRT monitors with 1152x864 resolutions, and 32-bit colour schemes. At the beginning of the study, we collected data on the participants' gender, age and the possible colour-deficiency problem. Other than that, the procedure was similar to the second pilot study. After rating half of the movies, the program prompted the participant to take a five-minute break, which he/she had the option to refuse or take. The experiment took 30 minutes for each participant to complete.

4.4.2 Results and Discussion

The hypothesis for this study was:

Hypothesis for the first main study: *A painterly rendered facial character sequence with the yellow-green (warm) colour palette is perceived more positive compared to the same sequence painted in the original colour palette. The same facial sequence painted in the blue (cool) colour palette is considered more negative compared to the sequence in the two above palettes. Therefore for the positive emotions such as joy and surprise, the depicted sequence with the yellow-green colour palette increases the perceived intensity of that emotion while the same sequence painted with the blue palette is perceived less intense. For the negative emotions such as anger and fear, the mentioned colour palettes have the opposite effect.*

We also expected that subjects will perceive combination of emotions rather than a single emotion or perceive changes in the intensity of the secondary emotions according to the colour palettes.

The results of the repeated measure (within-subject) ANOVA test with the three factors of emotion (4 levels), intensity (2 levels), and colour palette (4 levels), indicated a main effect of the colour palette (*$F(3,66) = 7.22, p<0.01$)* with an alpha level of 0.05 for the statistical significance. Based on Bonferroni's post-hoc test (Table 6), the mean ratings for both the cool and warm colour palettes (M≈ 2.85 , SD≈0.15) were significantly higher than the mean ratings for the original and paintednatural colour palettes (M≈2.6, SD≈0.14). In general, this does not confirm our hypothesis which is mainly about the difference between the cool and warm colour palettes.

The results also indicated an interaction of emotion*colourpalette with an F ratio of $F(9,198) = 2.12$, $p = .03$ indicating that the patterns of mean ratings across the different colour palettes depends on the emotion. Figure 19 shows the pattern of ratings for the four emotions.

Table 5-Results of repeated measure (within subject) ANOVA test for the first main study

Source		df	Mean Square	F	Sig.	Partial Eta Squared	Observed Power[a]
emotion	Greenhouse-Geisser	1.862	173.670	31.570	.000	.589	1.000
Error(emotion)	Greenhouse-Geisser	40.959	5.501				

intensity	Sphericity Assumed	1	283.514	167.766	.000	.884	1.000
Error(intensity)	Sphericity Assumed	22	1.690				
colourpalette	Sphericity Assumed	3	3.569	7.223	.000	.247	.978
Error(colourpalette)	Sphericity Assumed	66	.494				
emotion * intensity	Sphericity Assumed	3	4.156	4.876	.004	.181	.891
Error(emotion*intensity)	Sphericity Assumed	66	.852				
emotion * colourpalette	Sphericity Assumed	9	1.019	2.122	.029	.088	.870
Error(emotion*colourpalette)	Sphericity Assumed	198	.480				
intensity * colourpalette	Sphericity Assumed	3	.779	1.752	.165	.074	.437
Error(intensity*colourpalette)	Sphericity Assumed	66	.445				
emotion * intensity * colourpalette	Sphericity Assumed	9	.692	1.711	.089	.072	.771
Error(emotion*intensity*colourpalette)	Sphericity Assumed	198	.405				

a. Computed using alpha = .05

Table 6-Bonferroni's posthoc test for the four colour palettes in the first main study

Pairwise Comparisons

(I) colourpalette	(J) colourpalette	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	.264*	.088	.038	.010	.518
	3	.220*	.075	.047	.002	.437
	4	.005	.061	1.000	-.172	.183

	2	1	-.264*	.088	.038	-.518	-.010
		3	-.045	.058	1.000	-.212	.122
		4	-.259*	.083	.029	-.499	-.019
	3	1	-.220*	.075	.047	-.437	-.002
		2	.045	.058	1.000	-.122	.212
		4	-.214*	.071	.038	-.420	-.008
	4	1	-.005	.061	1.000	-.183	.172
		2	.259*	.083	.029	.019	.499
		3	.214*	.071	.038	.008	.420

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

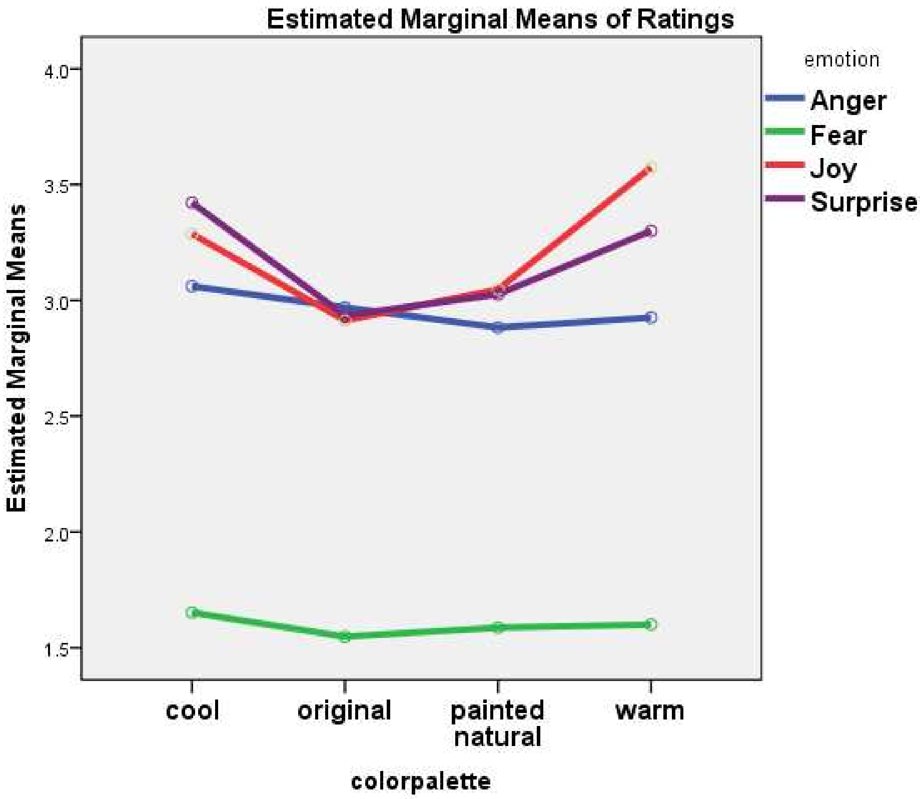

Figure 19- Mean ratings for the four colour palettes in the first main study

Looking at Figure 19, there is almost no effect of the colour palette for the anger and fear movies, while the surprise and joy movies have higher ratings for the warm and cool palettes. Moreover, one can notice that the effects of the warm (M=3.30, SD=0.18) and cool (M=3.42, SD=0.20) colour palettes were almost equal for the surprise movies while for the joy movies ratings for the warm palette (M=3.57, SD=0.21) were higher than the cool palette (M=3.29, SD=0.19). Thus, we conducted a separate repeated measure (within-subject) ANOVA test on the ratings for the joy movies with the two factors of intensity (or energy, 2 levels) and colour palette (4 levels). The results of the ANOVA test indicated a main effect of colour palette (*F(3,66)=3.88, p=0.000*). Table 8 on the results of the Bonferroni's post-hoc test shows that the warm (yellow-green) colour palette (M=3.57, SD=0.21) were perceived significantly more intense for the joy movies than the cool (blue) palette (M=3.29, SD=0.19), the paintednatural (M=3.05, SD=0.20), and finally the original palettes (M=2.91, SD=0.21). Figure 20 displays the pattern of ratings for the low and medium intensities in the joy movies.

Table 7- Results of repeated measure (within subject) ANOVA test on the joy ratings for the first main study

Source		df	Mean Square	F	Sig.	Partial Eta Squared	Observed Power[a]
intensity	Sphericity Assumed	1	90.440	182.963	.000	.893	1.000
Error(intensity)	Sphericity Assumed	22	.494				
colourpalette	Sphericity Assumed	3	3.876	10.373	.000	.320	.998
Error(colourpalette)	Sphericity Assumed	66	.374				
intensity * colourpalette	Sphericity Assumed	3	.775	2.872	.043	.115	.661

Error(intensity*colourpalette)	Sphericity Assumed	66	.270					

a. Computed using alpha = .05

Table 8-Bonferroni's posthoc test for the four palettes in the joy movies

Pairwise Comparisons

(I) colourpalette	(J) colourpalette	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	.374*	.125	.039	.013	.735
	3	.239	.130	.483	-.139	.617
	4	-.287*	.090	.026	-.549	-.025
2	1	-.374*	.125	.039	-.735	-.013
	3	-.135	.129	1.000	-.509	.239
	4	-.661*	.134	.000	-1.050	-.271
3	1	-.239	.130	.483	-.617	.139
	2	.135	.129	1.000	-.239	.509
	4	-.526*	.149	.011	-.957	-.095
4	1	.287*	.090	.026	.025	.549
	2	.661*	.134	.000	.271	1.050
	3	.526*	.149	.011	.095	.957

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

Pairwise Comparisons

(I) colourpalette	(J) colourpalette	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	.374*	.125	.039	.013	.735
	3	.239	.130	.483	-.139	.617
	4	-.287*	.090	.026	-.549	-.025
2	1	-.374*	.125	.039	-.735	-.013
	3	-.135	.129	1.000	-.509	.239
	4	-.661*	.134	.000	-1.050	-.271
3	1	-.239	.130	.483	-.617	.139
	2	.135	.129	1.000	-.239	.509
	4	-.526*	.149	.011	-.957	-.095
4	1	.287*	.090	.026	.025	.549
	2	.661*	.134	.000	.271	1.050
	3	.526*	.149	.011	.095	.957

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

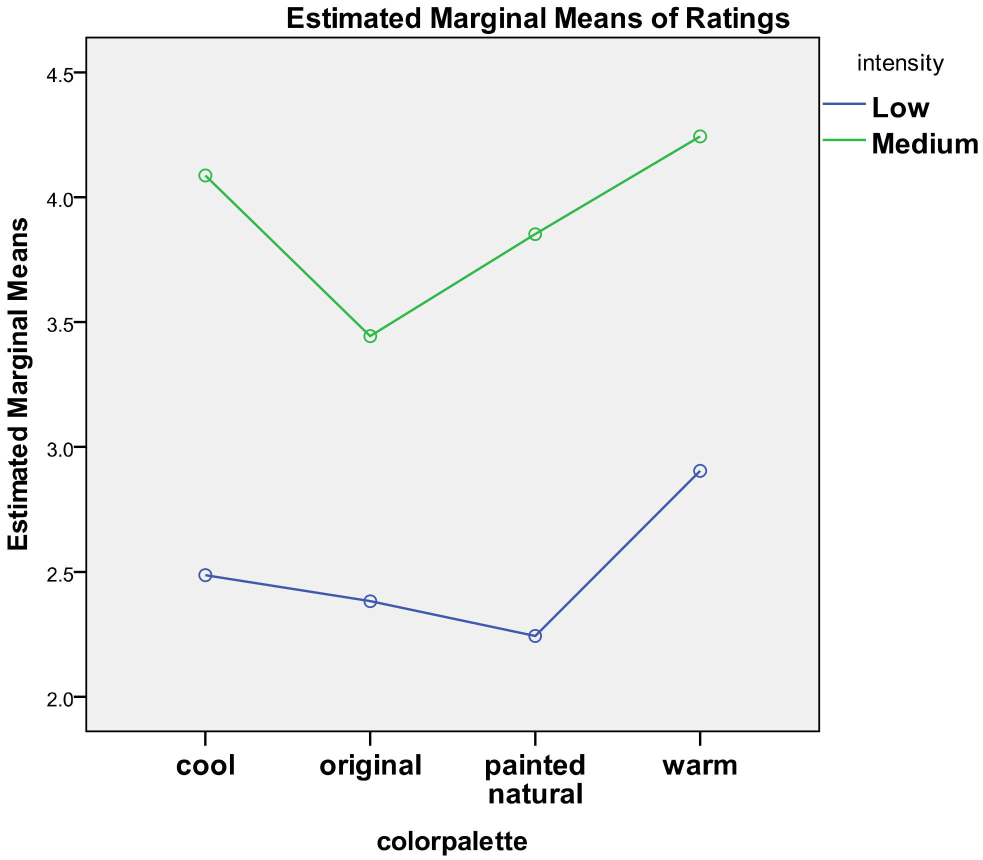

Figure 20- Ratings for the joy movies in the low and medium intensity (energy) levels

One final point to note is the obvious interference of surprise in the fear movies. This indicates that there is an issue with the configuration used for the fear and surprise expressions. However, for the CG (or natural) version and the painted natural version, fear was recognized which was probably the cause that the issue was not held in the pilot studies.

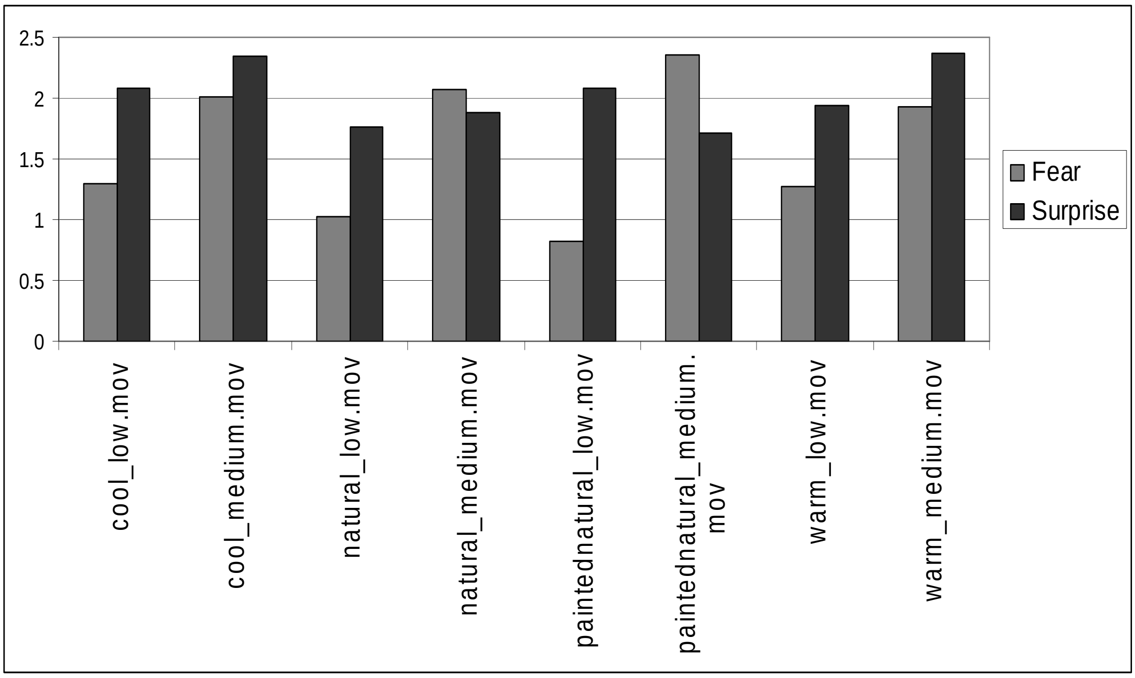

Figure 21-Ratings for the fear movies

4.5 Second Main Study

The objective of the second study was to explore the effect of the colour palette and the "center of interest" technique. Moreover, looking at the results of the first study, we suspected that the users might have guessed the hypothesis and/or variables of the study and responded accordingly. We tried to add more variability to the movies in order to eliminate such a factor. Thus, we added a new head model and a "center of interest" factor for the second study.

The study design was different from the first main study in several ways:

1. The CG movies (natural) were removed.
2. We replaced the low intensity movies in the experimental design with the high intensity movies.

3. A female head model was added to the design (see Figure 22).

4. We added a second version of each movie with a “center of interest” area around the eyes for all combinations of the expressions, the movie styles and the intensities for the two head models (female and male). We refer to the movies with a “center of interest” area around the eyes as the “focused-eye” movies (Figure 23, Figure 24). The complete experimental design for this study was:

   Head model (2)* Expression type (4)* Intensity (2)* Focus (2)* Colour palette (3) = 96 movie sequences.

5. Participants responded to each movie for four times.

6. We showed the extreme intensity of all the six basic expressions for the male head model to each participant at the beginning of the experiment.

7. We randomly divided the total 96 movies into two groups using a computer program. For each movie, we placed the female version of the movie randomly in one group and the male version in the other group. Half of the participants watched the movies in the first group and the other half watched the movies in the second group.

8. We saved the time for all of the users’ actions including the changes in the values of the sliders and the click data in a text file.

9. The movies were cut down to three seconds ending on the full expression without any black frame at the end, the subjects had the option to look at

the last frame of each movie as long as they wanted, replay the movie or go to the question form.

Figure 22- Nonfocused eye on the female head

Figure 23-Nonfocused eye on the male head

Figure 24-Focused eye on the male head

4.5.1 Method

Participants: 28 Undergraduate students (22 female, 6 male) participated in a 30 minutes user study for $5, they had the option to take a five-minute break in the middle of the study.

Movies: 48 movies were shown to each participant in four repetitions, resulting in 192 movies. For the movies with the “center of interest”, the “Painterly” program was used to paint the eyes in more details. Then we made the coloured versions of those frames using Adobe Photoshop CS3.

Procedure: The study was conducted at the UBC Vision Lab on two Samsung 14.5” CRT monitors with 1152x864 resolutions, 32-bit colour schemes. The two monitors were adjusted on the brightness and colour properties to display the colours similarly. The participants were assigned randomly to either group 1 or group 2. The procedure was exactly the same as the previous studies. The experiment took 30 minutes for each participant to complete.

4.5.2 Results and Discussion

The hypothesis for this study was:

Hypothesis for the second main study: *A colour effect similar to hypothesis for the first study is expected. For anger whose key feature lies in the eye region, subjects will perceive higher intensity in the sequences with the focused eyes.*

As we will describe below in more details, we were unable to confirm or reject our hypothesis because of the grouping effect in our data.

Figure 25 demonstrates the average of the ratings for the warm and cool colour palettes of both the focused and nonfocused movies. The data is aggregated over the two head models (female and male) and the two intensities (high and medium). As this chart does not show any specific trend in the data, we analyzed the female vs. male head models separately.

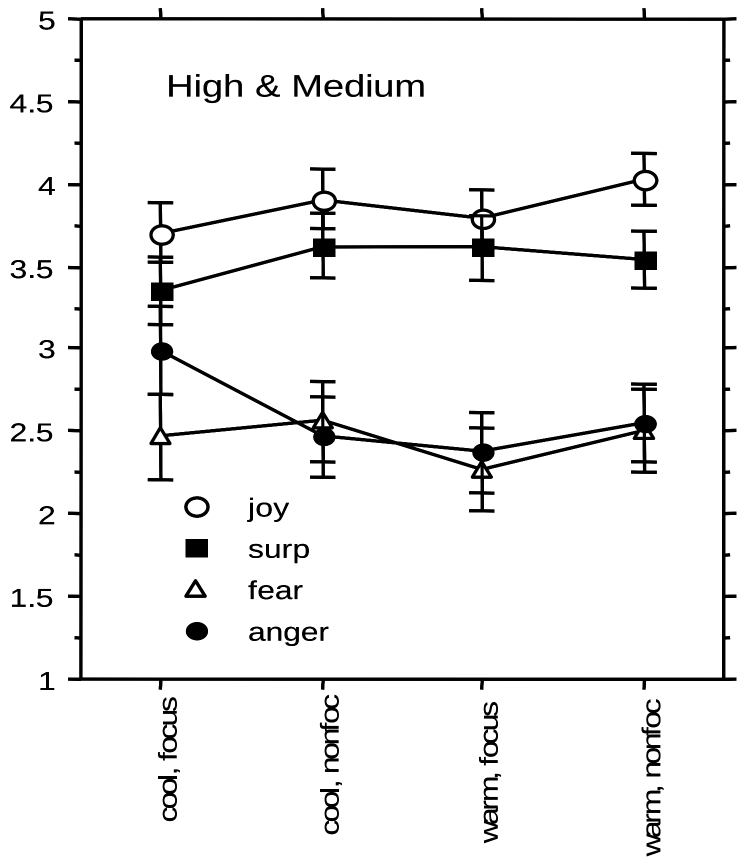

Figure 25- Ratings for each expression averaged over the female and male head models

Analyzing the anger and joy data for the female and the male heads separately resulted in the following figures (Figure 26, Figure 27):

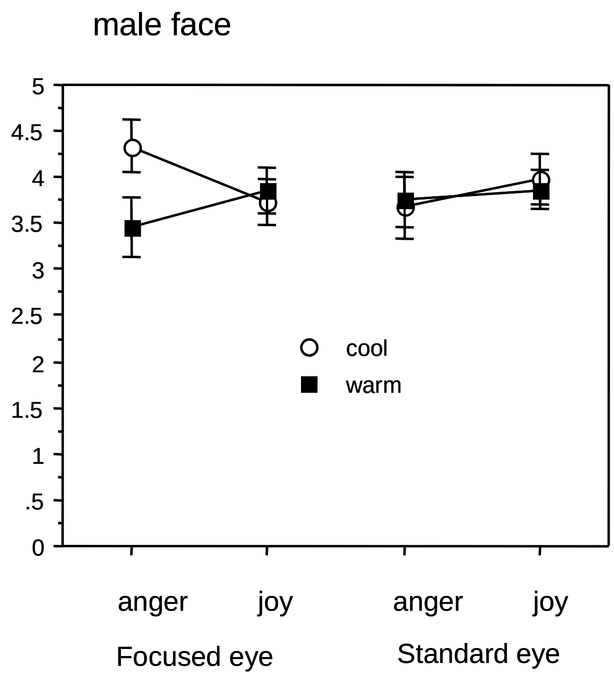

Figure 26-Anger and joy ratings for the male head

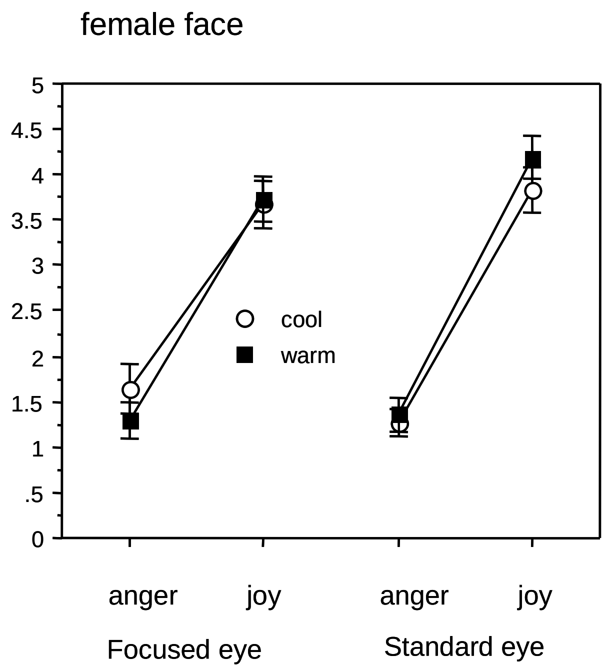

Figure 27-Anger and joy ratings for the female head

According to these charts:

1. The female head model was not judged as angry as the male.

2. The cool anger is more compelling than the warm anger, but only for the focused eye version. The reason could be that the eye region is very important in recognizing anger. The effect is stronger for the male head, but perhaps because the female model was perceived less angry in the first place.

3. The warm joy is more compelling than the cool joy but only for the female head with the standard (unfocused) eye. This could be because the female face seemed kinder/less angry compared to the male face.

In addition, the followings are our observations from the mean chart for each movie:

1) The patterns of ratings are different between the two head models, especially for the joy and surprise movies (Figure A 1, Figure A 2).

2) For the fear movies on the male head, the subjects mistakenly recognized surprise especially for medium intensity movies (Figure 28).

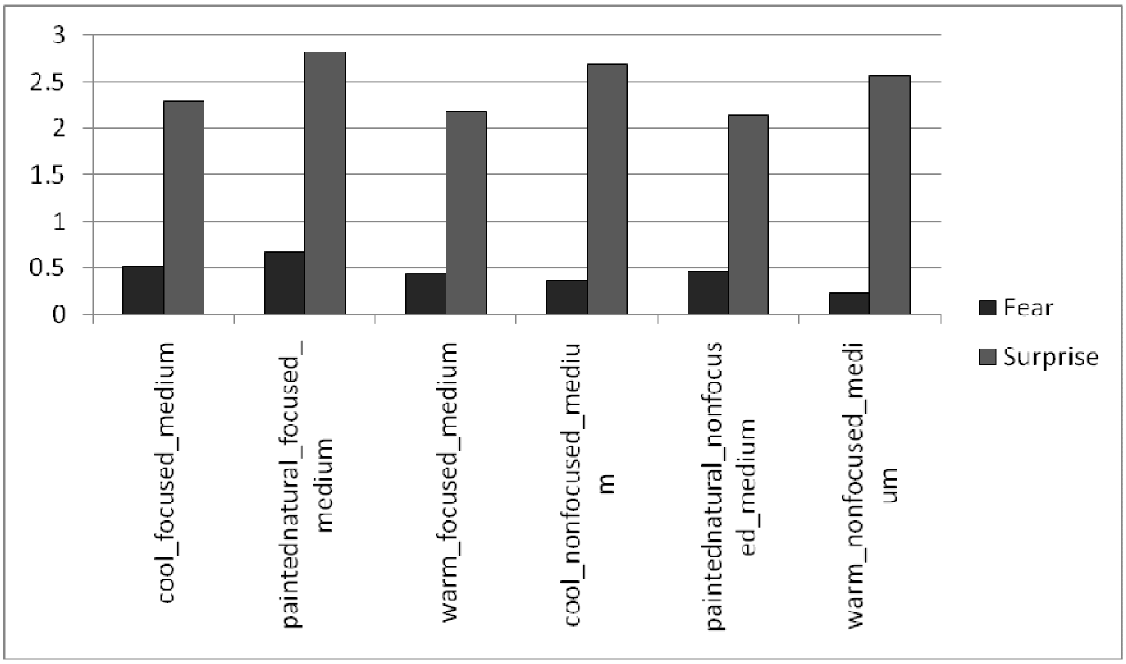

Figure 28-Fear and surprise ratings for the fear movies in the medium intensity

We analyzed the data for the two groups separately and realized that a grouping effect have confounded the data. Figure 29 shows the average ratings for each group.

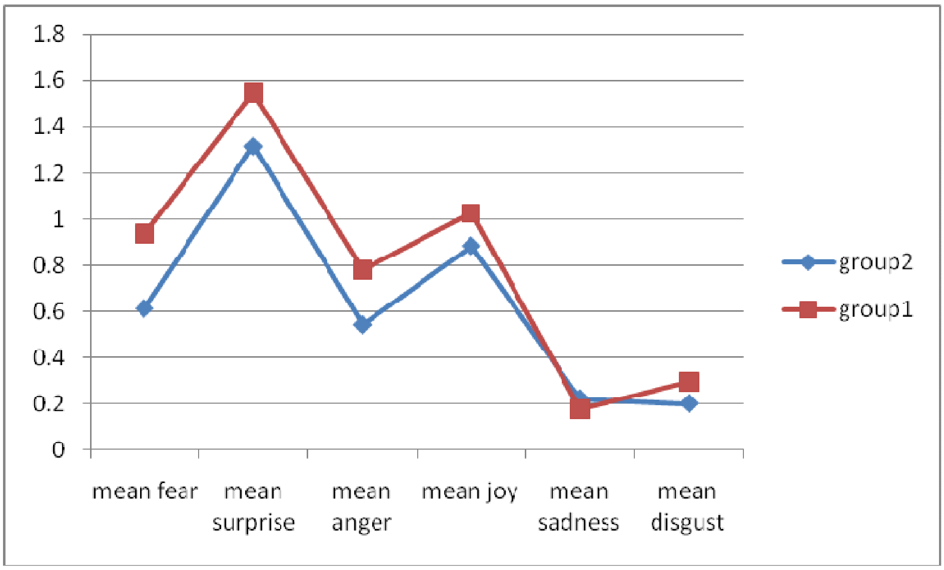

Figure 29- Mean of ratings for the two groups

Based on Figure 29, group 1's ratings are higher than group 2 which points out the potential undesirable impact of grouping on the ratings. The assignment of the female and male versions of the movies to the two groups was randomized in order to avoid such group effect but it caused more noise in the data.

Based on all of the above analysis, we decided that the data of the second study was confounded. Some of the causes can be:

Using two head models with different underlying mesh structure resulted in the different expressions for the two head models. For instance, we noted that because of the difference between the models' underlying meshes, during animation to the extreme position, the models appear to move to that extreme differently (e.g. eye brow movement was faster on the male head than on the female head). In addition, we randomly assigned the female and male versions to two groups. Since the users' ratings were relative to the other movies that they had watched, having different combinations of male and female movies made the comparison of the users' ratings very difficult. Therefore, due to the errors/noises in the results of the second main study, the data was not suitable for further analysis.

4.6 Third Pilot Study

In spite of the errors in the data for the last study, the analysis of the results from the previous studies revealed that the colour palette affects the ratings for the facial expressions but the results did not follow our hypothesis. As mentioned in section 3.3.1.3, we had designed the colour palettes based on art theories on combining cool and warm colours for a portrait painting. One explanation for the results is that separating the colour space into the warm and cool palettes does not result in the primary elements required for a controlled experiment. While artists use and talk about warm and cool palettes and we have shown this colour grouping has an effect on emotion, we felt that a more controlled and scientifically accurate grouping of colours was needed to examine our hypothesis. Thus, for this study, we modified the palettes using the data from the past user studies on colours. In particular, a study by da Pos and Green-Armytage (2007) was closely related to our study, which informed the design of our following studies significantly. da Pos and Green-Armytage (2007) asked two groups of designers to choose a combination of three colours and then a single colour for each of the six basic expressions. In general, they found high consensus among the designers in associating colours to the facial expressions.

da Pos and Green-Armytage (2007) provided the chosen colour combinations as well as the analysis of the general patterns of responses in their paper. According to their analysis, the colours for joy and surprise are mostly in the yellow-orange range and saturated, the colours for anger are black-red while the colours for fear and sadness are mostly gray-blue and unsaturated compared to joy, surprise and anger. We used this information as the general guidelines for designing our colour palettes for the four expressions. da Pos and Green-Armytage (2007) also calculated the average of the colours chosen by the subjects in the *La*b** colour system. The luminance component of our choices for colours corresponds to these average values but *a** and *b** values are a bit different.

Table 9 contains the average *La*b** values for the colours provided in da Pos and Green-Armytage's paper (2007) and the corresponding colours in the *La*b** system.

Table 9- La*b* values for the four expressions and the result colour

Emotion	L	a*	b*	Result colour
Anger	30	22	10	
Fear	50	8	10	

Surprise	60	17	42	
joy	60	15	30	

As displayed in this table, the average values do not provide much insight for designing the colour palettes. Therefore, we used the actual colour combinations provided in the paper as a guideline for our choices of colour palettes with considering the above average values. The following figure shows the colour combinations provided in da Pos and Green-Armytage's paper (2007):

Figure 30- Colour combinations chosen by designers for the six basic expressions (from (da Pos & Green-Armytage, 2007))

Accordingly, the following figures are the four colour palettes that we designed for the third pilot study:

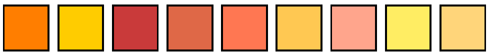

Figure 31-Colour palette for the warm-light movies (Congruent with joy and surprise)

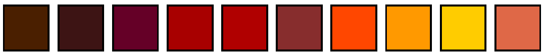

Figure 32-Colour palette for the warm-dark movies (Congruent with anger)

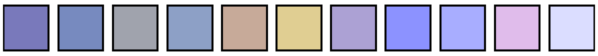

Figure 33-Colour palette for the cool-light movies (Congruent with fear)

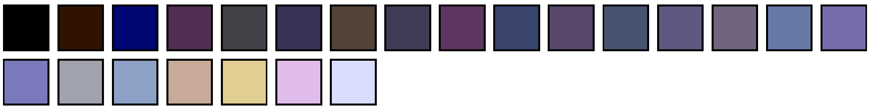

Figure 34- Colour palette for the cool-dark movies

In addition to the above colour palettes, we had an original colour palette that used the colour from the CG frame for painting the image. Therefore, the five colour palettes for this pilot study were warm-light, warm-dark, cool-light, cool-dark, and the original palette (see Figure 35). The warm-light palette is based on the colour combinations for joy and surprise. We anticipated that this palette boosts the intensity perceived for joy and surprise. The warm-dark colour palette was designed based on the colour combinations for anger. The cool-light palette was designed to increase the intensity perceived for fear and finally, we chose the cool-dark palette to explore the effect of brightness. We used two levels of brightness, light and dark, for the warm and cool palettes to examine whether the observed changes in the ratings are mainly because of the hue or the brightness differences also affect the ratings.

Figure 35- Five colour palettes for the third pilot study

In addition, in the previous studies, we had applied the colour palettes to both the face and the background. However, for this study we decided to preserve the colour of the background, which was a mid-tone gray colour, and apply the different colour palettes just to the face model. We believe that in this way, the results of the study correspond more to the changes in the face and the facial expressions compared to the past studies in which we had the additional effect of the environment.

For this pilot study, we used still images instead of the video sequences since we realized that the still images give a good intuition about the effect of the colour palettes on the facial expressions with less time and effort. We expected to observe a similar effect in both still images and video sequences. Thus, we conducted this pilot study on the still images to test the appropriateness and impact of the chosen colour palettes on the facial expressions.

4.6.1 Method

Participants: 15 graduate students (6 female, 9 male) participated in a 30 minutes user study voluntarily. They had the option to take a five-minute break in the middle of the study.

Images: each participant watched 38 images in three repetitions, resulting in 114 ratings. We used the “Painterly” program to paint the images in the five chosen colour palettes (warm-dark, warm-light, original-palette, cool-dark, and cool-light). We used the female head model from the previous study and the images displayed the full-blown versions of the four expressions in the medium and high intensities.

Procedure: The study was conducted at SFU using a 14” Toshiba laptop. The procedure was exactly the same as the procedure in the previous studies, except that the sample expressions were also still images. The experiment took approximately 30 minutes for each participant to complete.

4.6.2 Results and Discussion

The hypothesis for this pilot study was:

Hypothesis for the third pilot study: *For each of the four emotions examined, the painterly-rendered image with the congruent colour palette will increase the intensity perceived for that emotion compared to the perceived intensity for the same facial expression painted with the original palette.*

Furthermore, painting the same facial expression with the incongruent colour palettes will either decrease the intensity perceived for that emotion or not change it compared to the ratings for the original palette sequence.

The test of repeated measure (within subject) ANOVA was taken with the three factors of emotion, energy (intensity), and congruency. All the effects were statistically significant at the .05 significance level. The results indicated a main effect of congruency with an *F* ratio of $F(2,28) = 8.86$, $p = .001$. The Bonferroni's posthoc test (Table 11) indicates that the mean rating for the congruent colour palettes (M=3.74, SD=0.19) was significantly higher than the mean rating for the incongruent colour palettes (M=3.24, SD=0.18). The results also indicate an interaction of emotion*congruency with an *F* ratio of $F(6\ ,84) = 2.83$, $p = .015$ indicating that the patterns of mean ratings for the different congruency levels were different depending on the emotion (see Table 11). Figure 36 demonstrates the emotion*congruency effect; the ratings for the original colour palette is higher than ratings of the incongruent colour palette for the joy and surprise movies, while these two palettes (original and incongruent) have similar ratings for the anger and fear movies.

Table 10- Results of repeated measure (within subject) ANOVA test for the third pilot study

Source		df	Mean Square	F	Sig.	Partial Eta Squared	Observed Power[a]
Emotion	Greenhouse-Geisser	2.031	45.204	5.680	.008	.289	.827
Error(emotion)	Greenhouse-Geisser	28.428	7.958				

energy	Sphericity Assumed	1	107.463	100.958	.000	.878	1.000
Error(energy)	Sphericity Assumed	14	1.064				
congruency	Sphericity Assumed	2	7.657	8.861	.001	.388	.955
Error(congruency)	Sphericity Assumed	28	.864				
emotion * energy	Sphericity Assumed	3	3.397	2.525	.070	.153	.583
Error(emotion*energy)	Sphericity Assumed	42	1.345				
emotion * congruency	Sphericity Assumed	6	2.526	2.828	.015	.168	.863
Error(emotion*congruency)	Sphericity Assumed	84	.893				
energy * congruency	Sphericity Assumed	2	1.446	1.919	.166	.121	.364
Error(energy*congruency)	Sphericity Assumed	28	.754				
emotion * energy * congruency	Sphericity Assumed	6	.558	1.113	.362	.074	.416
Error(emotion*energy*congruency)	Sphericity Assumed	84	.502				

a. Computed using alpha = .05

Table 11- Bonferroni's posthoc test for the third pilot study

Pairwise Comparisons

(I) congruency	(J) congruency	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	.235	.123	.232	-.100	.571
	3	-.269	.118	.116	-.590	.051
2	1	-.235	.123	.232	-.571	.100
	3	-.505*	.118	.002	-.827	-.183

3	1	.269	.118	.116	-.051	.590
	2	.505*	.118	.002	.183	.827

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

*. The mean difference is significant at the .05 level.

Figure 36 displays the mean chart of the subjects' ratings for the three congruency levels (the original, the incongruent, and the congruent palettes):

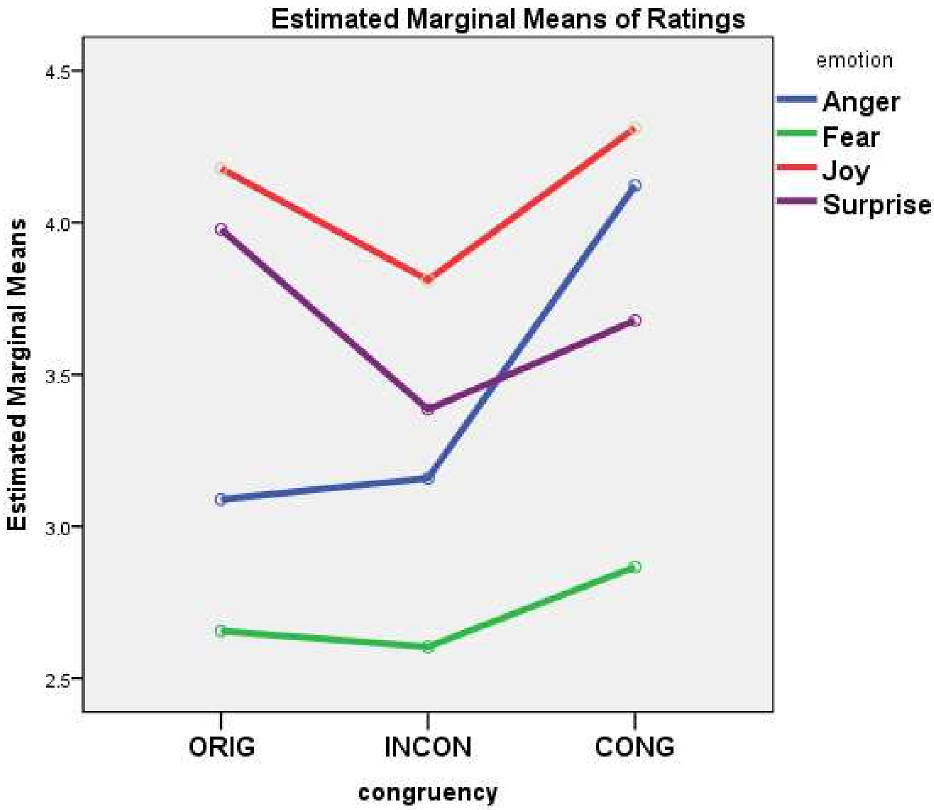

Figure 36-Ratings for CONG/INCON/ORIG palettes in the third pilot study

According to this graph, for all of the emotions, the congruent colour palette has higher ratings compared to the incongruent colour palettes (similar to the results of the ANOVA test). Moreover, except for surprise, the congruent palette has the highest ratings among the three palettes. For surprise, the original colour palette has the overall highest ratings followed by the congruent and the incongruent colour palettes.

Figure 37 shows that the congruent-incongruent effect is about the same size for the high and low energy levels, although the original palette is more like the incongruent palettes (INCON) in the medium intensity and like the congruent palette (CONG) in the high intensity/energy level.

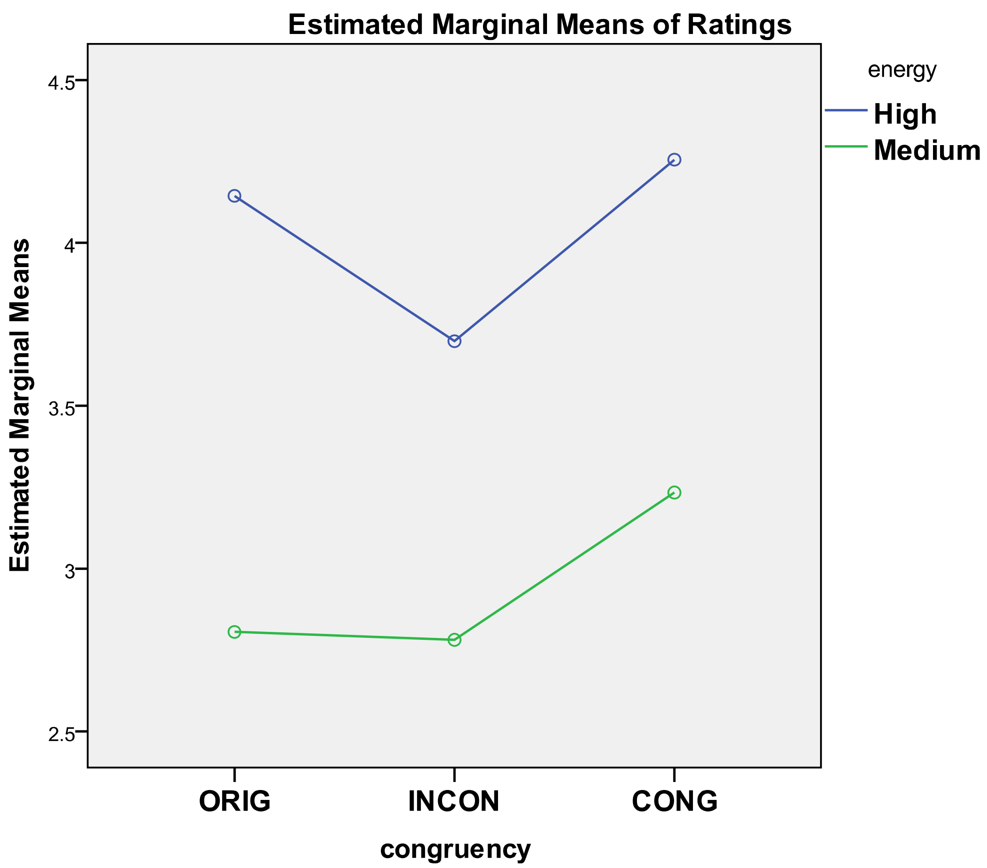

Figure 37-Ratings for CONG/INCON/ORIG palettes in the high and medium intensity

In addition, Figure 38 shows that the energy effect is largest for anger and surprise than for joy and fear.

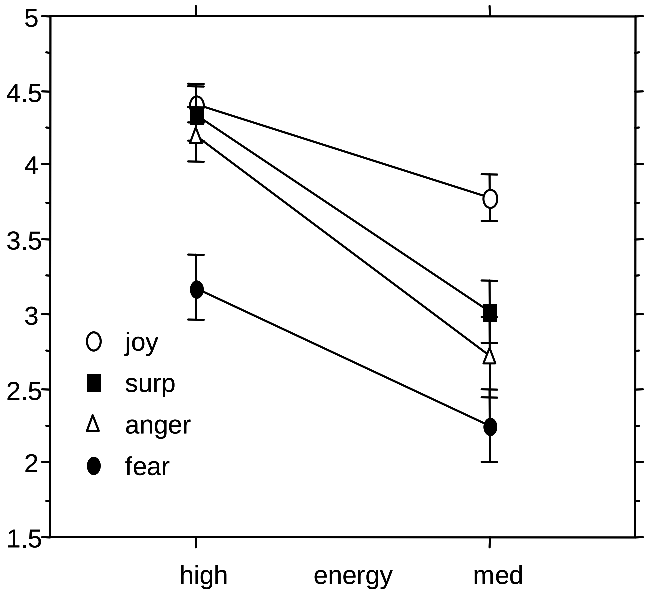

Figure 38- Energy effect for different emotions

Analyzing the data for each emotion, we found the following points interesting to note:

1) For the joy movies, the warm-dark palette (one of the incongruent palettes) has the lowest ratings. All the other palettes (including the congruent palette and all the other incongruent palettes) have similar ratings especially in the medium intensity.

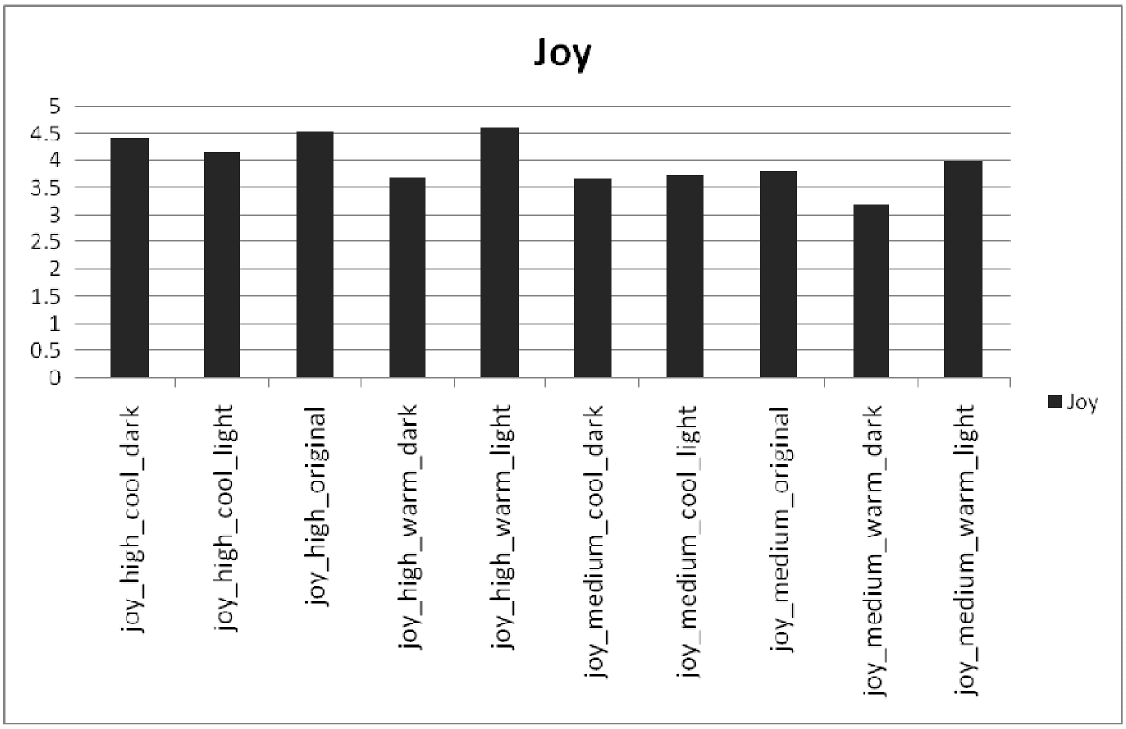

Figure 39- Ratings for the joy movies

2) In general, we don't see the intensity effect in the secondary emotions perceived.

3) Similar to the results of the previous studies, surprise is the secondary emotion for fear and vice versa and in many cases as the rating for the primary emotion decreases, the rating of the secondary emotion increases (Figure 40, Figure 41).

4) Sadness is the tertiary emotion for the fear movies; and the sadness perceived for the warm-dark palette (the congruent colour for anger) has the lowest ratings (Figure 40).

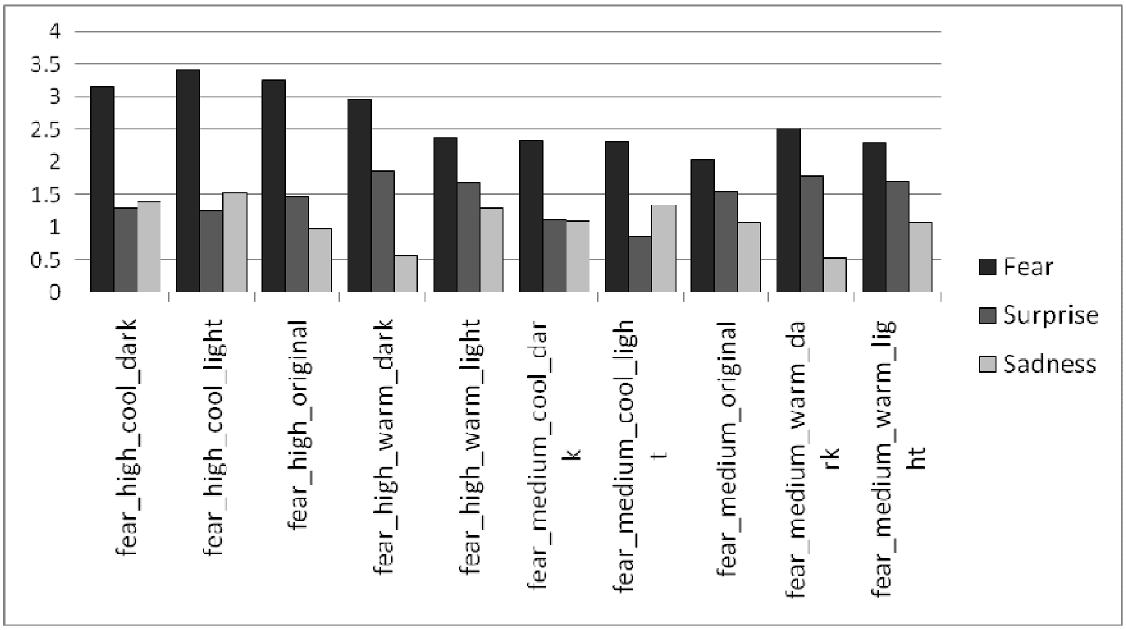

Figure 40-Secondary and tertiary ratings for the fear movies

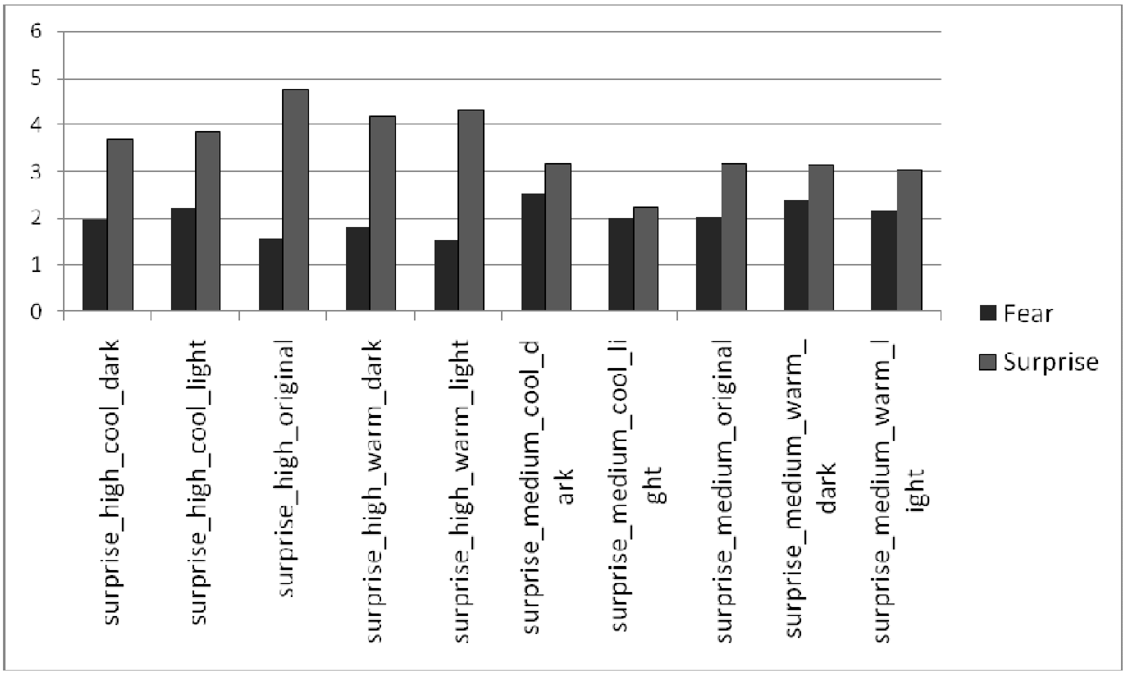

Figure 41-Secondary ratings for the surprise movies

4.7 The Final Study

Based on the results of the third pilot study, we decided to use a similar design to the third pilot study for the animated sequences in the final study. However, we aligned the palettes more with the data from da Pos and Green-Armytage's paper (2007). Here is brief description of the changes:

We made two changes to the colour palettes: 1) we removed the cool-dark colour palette, as it did not correspond to any of the four chosen expressions. This palette was added to the previous study to examine the effect of brightness. For this study, we decided to focus on the impact of the proposed congruent colours for the emotions by da Pos and Green-Armytage (2007)and investigate the effect of brightness in a follow up study, and 2) we adjusted the colour palette for the fear expression. da Pos and Green-Armytage determined the average colour chosen by designers for each of the six facial expression in the *La*b** system. In order to make sure that our palettes correspond to the proposed colours in the paper, we calculated the average colour of the neutral face painted in each colour palette. Table 2 shows both the average values for the face with our colour palettes and the average values provided in the da Pos and Green-Armytage's paper (2007) in the *La*b** colour system. Comparing these values, we realized that the *a* and *b* values for the fear palette does not match the provided values in the paper. The colour palette we used in the third pilot study had a blue tone while the proposed colour in that paper had an unsaturated red tone. Therefore, we modified the congruent colour palette for fear in order to get a better match for the values provided in the paper. Figure 42 and Figure 43 display the fear palette and all colour palettes used for the final study.

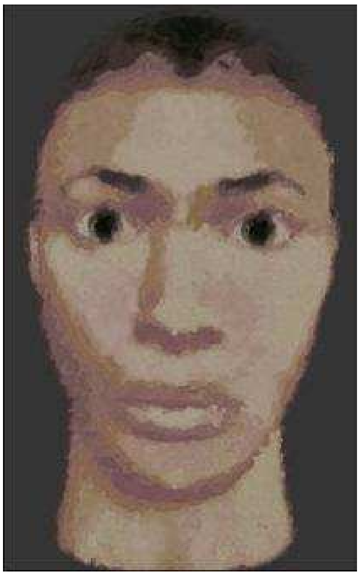

Figure 42- Pale colour palette for the fear expression

Joy & surprise Anger Fear Base

Figure 43- Four colour palettes for the final study

In addition to the changes to colour palettes, we modified the brush properties for the final study, which affect the texture appearance in the output painting. According to previous affective studies and art literature (Colton et al., 2008; Duke et al., 2003; Halper et al., 2003; Hevner, 1935; Shugrina et al., 2006), harsh angles and jaggy lines convey vigorousity, power, fury and agitation while smooth curves are associated with serenity, laziness, and tender sentimentality. Thus, we decided to use two brush types: jaggy and blurry. We had preliminary hypothesis about the effect of these two brush styles but we mainly intended to explore their effects on the users' perception. The addition of this factor also increased the variability of the movies, which was helpful for hiding the main hypothesis of the study from the users, as we will describe below in more detail.

After analysing the data from the last pilot study, we suspected that the subjects might have realized the hypothesis of the study and responded accordingly. The experimental psychology refers to this phenomenon/artefact as the experimenter's demand. The implication of having such an artefact in the pilot study is that the data from the last pilot study would just reveal that the subjects had found the colour palettes and the facial expressions related. This is different from our question about the effect of the colour palettes on the type and intensity perceived for the facial expressions. To reduce the effect of such an artefact, we decided to add variability to our movies. Furthermore, at the beginning of each session of the study, the investigator told the participant that the set of movies contain some settle variations as well as obvious variations such as colour changes and we are interested in the combined effect of the variations, thus the participant should respond based on the his/her impression.

Similar to the third pilot study, we used the female head and left out the male head. The main reason was that the facial expressions on these two head models did not match appropriately because of their different underlying mesh structures. One possibility was to use two female and male head models with the same underlying mesh structure but with different textures. However, the result models were so similar that would not help with the generalizability of the experiment. In addition, adding a second model would result in a high number of movies, which would raise the need for grouping. Thus, we decided to use only the female model, since it does not exhibit specific female/male characteristics.

Some of the differences between this study and the previous pilot study were:

- Subjects watched a set of movies instead of still images
- We used two brush styles, blurry and jaggy, created by different settings for the size and curvature of the brush. A larger brush size with higher curvature value resulted in a "blurry" texture while a smaller brush with less curvature generated a "jaggy" effect. Figure 8Figure 44 shows an example of these brush styles.

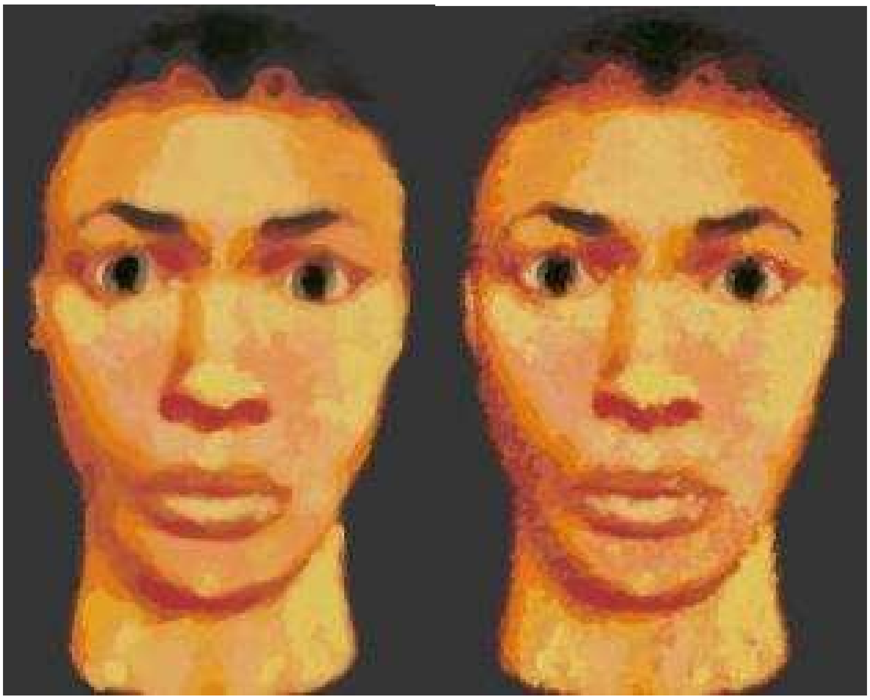

Figure 44-blurry and jaggy brush styles

- The brush style for the final study was a circular brush similar to the earlier studies. Only for the third pilot study, we used a texture brush, which resulted in some noise on the background.
- Four colour palette were examined in this study (Figure 43).

4.7.1 Method

Participants: 22 Undergraduate students (17 female, 5 male) participated in a 30 minutes user study for course credit, they had the option to take a five-minute break in the middle of the study.

Movies: 64 movies were shown to each participant in three repetitions, resulting in 192 ratings. We used the “Painterly” program to paint the frames of the movies in the four chosen colour palettes (warm-dark, warm-light, original palette, and palecolour). The set of movies included the female head model displaying four chosen expressions(4) in the medium and high intensities (2), and painted with four colour palettes (4) and two brush styles (2).(4*2*4*2=64)

Procedure: The study was conducted at the UBC Vision Lab on two Samsung 14.5 inches CRT monitors with the resolution of 1152x864 at 32-bit colour schemes. We adjusted the settings of the two monitors to have the same colour output. The experiment took approximately 45 minutes for each participant to complete. The procedure for the study was similar to the previous studies. The only difference was that the investigator told the participant that the movies contain obvious colour changes as well as other settle differences and we are interested in the effect of the combination. Thus, the participant should respond based on his/her first impression of the movies.

4.7.2 Results and Discussion

The hypothesis for this study was the same as the hypothesis for the third pilot study but on animated character sequences:

Hypothesis for the final study: *For each of the four emotions examined, the painterly rendered facial sequence with the congruent colour palette will increase the perceived intensity of that emotion compared to the perceived intensity for the same facial sequence painted with the original palette. Furthermore, the painterly rendering of the same facial character sequence with the incongruent colour palettes will either decrease the intensity perceived for* *that emotion or does not change it compared to the ratings for the original palette sequence.*

The test of repeated measure (within subject) ANOVA was taken with four factors of emotion (4 levels), intensity (2 levels), brush style (2 levels) and congruency (3 levels). Table 12 displays the results of the ANOVA test. All effects were statistically significant at the .05 significance level. The results indicated an interaction effect of emotion* congruency with an *F* ratio of $F(6,126) = 7.8$, $p = .000$. This result indicates that the effects of the original, congruent, and incongruent palettes were different for the four emotions used. According to Figure 45, the anger movies have higher ratings for the congruent colour palette (M=3.12, SD=2.5) in comparison to the incongruent colour palette (M=2.53, SD=0.22) and original colour palette (M=2.63, SD=0.23). Similarly for joy movies, congruent colour palette (M=3.85, SD=0.17) has higher rating than the incongruent colour palette (M=3.66, SD=0.22) and original colour palette (M= 3.56, SD=0.22). While the results of the ANOVA test showed higher order interactions as well, the above interaction was the most relevant in terms of answering our research question and hypothesis.

In contrast, the data for the fear movies indicate higher ratings for the original (M=2.36, SD=0.15) and then the incongruent (M=2.04, SD=0.18) colour palettes compared to the congruent colour palette (M=1.78, SD=0.24). The pattern of the ratings for the surprise movies were almost constant for all colour palettes, with the following values for the original (M=3.66, SD=0.21), congruent

(M=3.67, SD=0.15) and incongruent (M=3.70, SD=0.19) colour palettes. The result of the ANOVA test does not show any significant effect of the brush style.

Table 12- Results of repeated measure (within-subject) ANOVA test for the final study

Source		df	Mean Square	F	Sig.	Partial Eta Squared	Observed Power[a]
emotion	Sphericity Assumed	3	164.565	22.430	.000	.516	1.000
Error(emotion)	Sphericity Assumed	63	7.337				
energy	Sphericity Assumed	1	414.377	159.958	.000	.884	1.000
Error(energy)	Sphericity Assumed	21	2.591				
brushstyle	Sphericity Assumed	1	.648	1.118	.302	.051	.172
Error(brushstyle)	Sphericity Assumed	21	.580				
congruency	Sphericity Assumed	2	1.368	1.707	.194	.075	.339
Error(congruency)	Sphericity Assumed	42	.801				
emotion * energy	Sphericity Assumed	3	1.628	1.594	.200	.071	.400
Error(emotion*energy)	Sphericity Assumed	63	1.021				
emotion * brushstyle	Sphericity Assumed	3	.732	1.385	.256	.062	.351
Error(emotion*brushstyle)	Sphericity Assumed	63	.528				
energy * brushstyle	Sphericity Assumed	1	.553	.773	.389	.035	.134

Error(energy*brushstyle)	Sphericity Assumed	21	.716				
emotion * energy * brushstyle	Sphericity Assumed	3	4.090	7.611	.000	.266	.983
Error(emotion*energy*brushstyle)	Sphericity Assumed	63	.537				
emotion * congruency	Sphericity Assumed	6	5.646	7.804	.000	.271	1.000
Error(emotion*congruency)	Sphericity Assumed	126	.724				
energy * congruency	Sphericity Assumed	2	.525	1.036	.364	.047	.219
Error(energy*congruency)	Sphericity Assumed	42	.506				
emotion * energy * congruency	Sphericity Assumed	6	.936	2.120	.055	.092	.742
Error(emotion*energy*congruency)	Sphericity Assumed	126	.442				
brushstyle * congruency	Sphericity Assumed	2	1.825	5.085	.011	.195	.792
Error(brushstyle*congruency)	Sphericity Assumed	42	.359				
emotion * brushstyle * congruency	Greenhouse-Geisser	4.210	1.388	2.152	.078	.093	.630
Error(emotion*brushstyle*congruency)	Greenhouse-Geisser	88.411	.645				
energy * brushstyle * congruency	Sphericity Assumed	2	1.111	1.901	.162	.083	.373
Error(energy*brushstyle*congruency)	Sphericity Assumed	42	.584				
emotion * energy * brushstyle * congruency	Sphericity Assumed	6	.855	1.618	.147	.072	.603
Error(emotion*energy*brushstyle*congruency)	Sphericity Assumed	126	.528				

a. Computed using alpha = .05

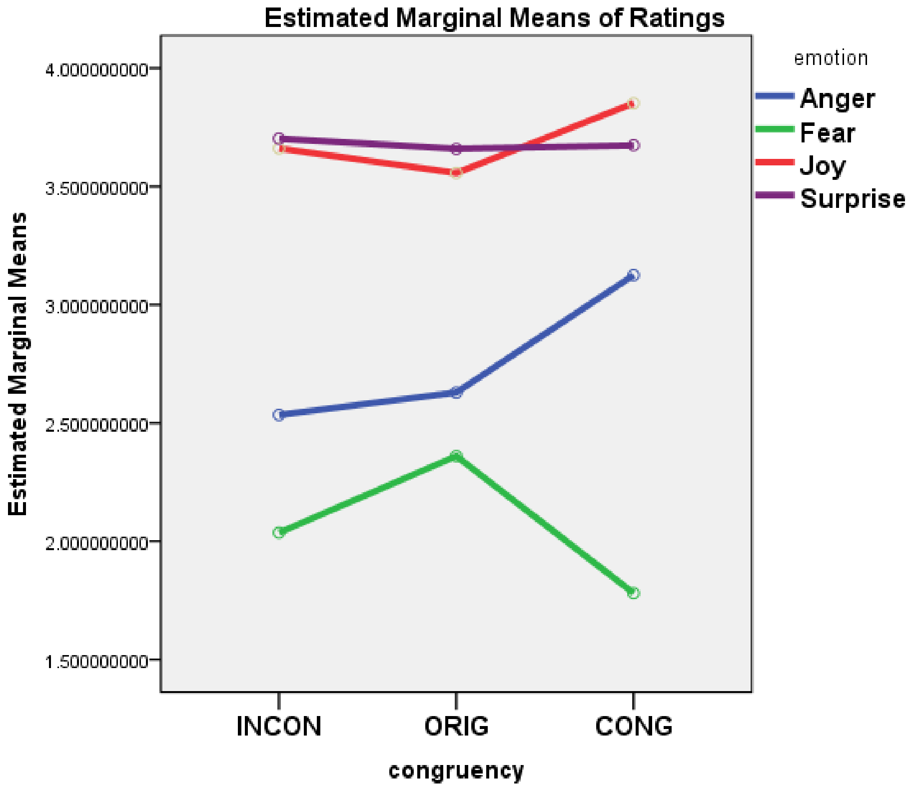

Figure 45- Interaction plot for emotion*congruency in the final study

These results confirm our hypothesis for the anger and joy cases. For the fear movies, the relationship between the original palette and the congruent palette (palecolour) is interesting. These two palettes have very similar looks (Figure 46) but the pale colour palette appears as less saturated. A follow-up analysis of the average colour for these two palettes in the HSB (Hue, Saturation, Brightness) colour system revealed that the main difference of the two colour palettes is in their saturation values (Table 13). Thus, a possible reason for the unanticipated pattern of ratings in the fear movies might be the inappropriate saturation for this palette compared to the original palette. According to these values the pale colour palette had the lowest saturation among all. A follow-up study can examine the effect of saturation on the users' ratings.

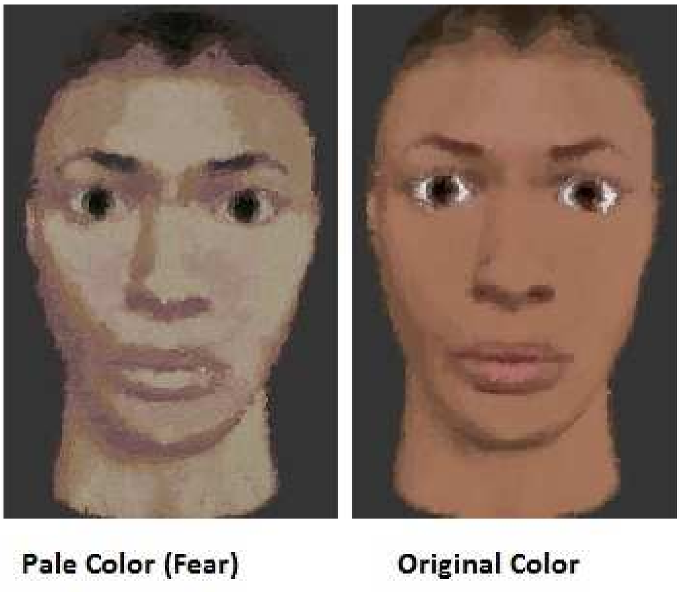

Figure 46- Pale vs. original colour palettes

Table 13-Average colours for the palettes used in HSB colour system

Colour palettes	Hue	Saturation	Brightness
Original colour	19	43	57
Pale colour (congruent with fear)	25	27	53
Warm dark (congruent with anger)	16	82	55
Warm light (congruent with joy)	29	66	78

Another reason for the ratings of the fear movies can be due to less consensus among the designers in the colours chosen in da Pos and Green-Armitage's study (2007) for the fear expression. Such variation suggests that a clear consensus might not exist for the colour associated with the fear emotion.

For the surprise movies, the pattern of ratings was different for the two intensity levels and overall did not follow our hypothesis. However, in both cases, the original and congruent palettes have similar ratings and in the high energy (intensity) level, these values were higher than the rating for the incongruent palette.

One possible explanation for the differences between the results of our study and da Pos and Green-Armytage's study (2007) is that the surprise expression in their study corresponds to an amused/pleasant surprise while in our studies, the facial configuration for surprise is close to a shocked/unpleasant surprise. Although Ekman and Friesman in their book, Unmasking the Face: A Guide to Recognizing Emotions from Facial Expressions (2003), provided both images as the facial configurations for surprise(see Figure 47), we believe these two images belong to two variations in the surprise family of expressions. This also explains why the colours chosen for surprise in da Pos and Green-Armytage's study were close to the colours for the joy expression. In contrast, for our experiment, the congruent colour palette for fear might have been a more appropriate palette for the surprise movies. Follow-up studies with the palettes adjusted for fear and surprise can address this hypothesis.

Figure 47- Two surprise expressions from (Ekman & Friesen, 2003)

In terms of the secondary emotions, subjects identified disgust as the secondary emotion for the anger movies. However, the ratings for disgust were almost constant across the two intensity levels. The fear and surprise movies had two noticeable ratings: surprise and fear. Aggregating the fear and surprise values over the two intensity levels gives another possible explanation of the results. As shown in Figure 48 and Figure 49, in contrast to the other three emotions, the fear and surprise ratings for the surprise movies are constant for all the colour palettes and brush styles. We did not expect such a constant trend in the ratings. This indicates the colour palette did not have any noticeable impact on the intensity perceived for the surprise movies.

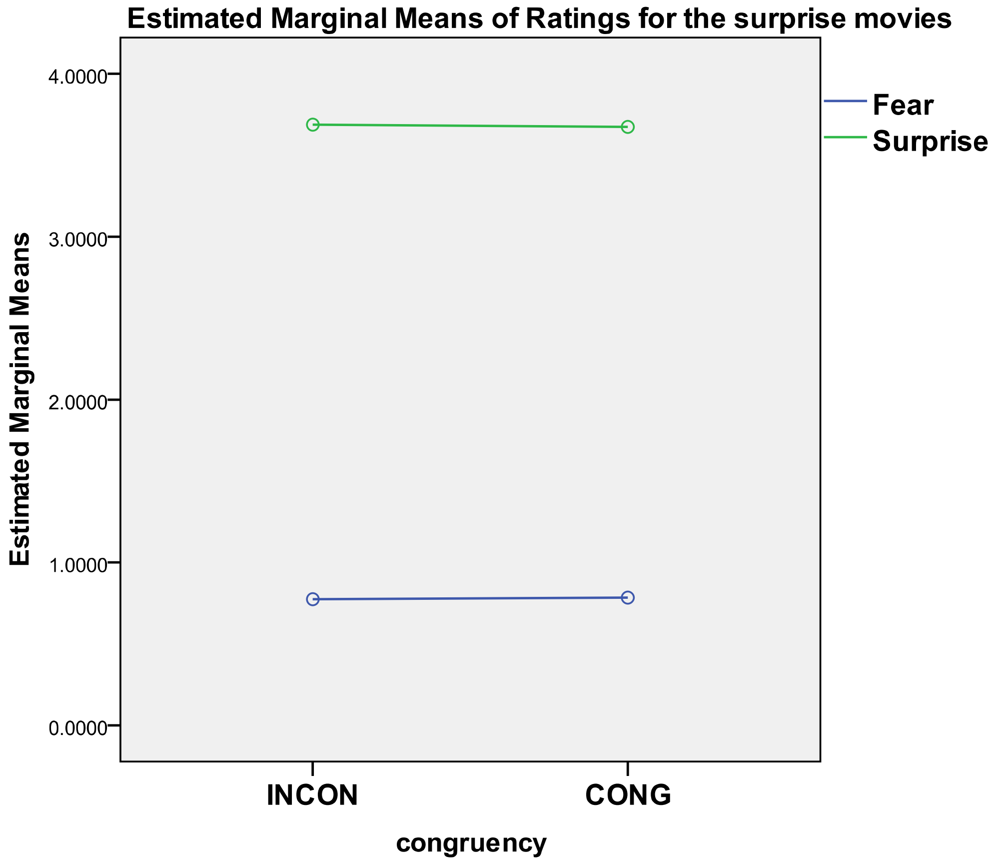

Figure 48- Fear and surprise ratings for the surprise movies (averaged over the two intensities and the two brush styles)

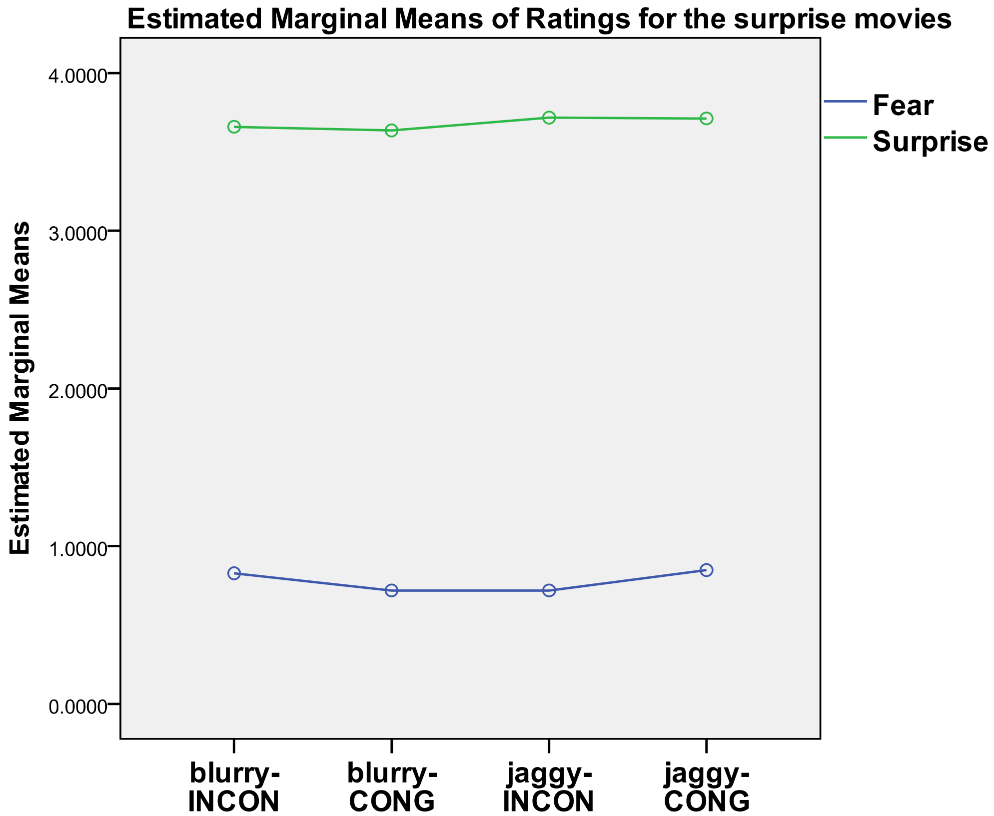

Figure 49- Fear and surprise ratings for the surprise movies (showing the two brush styles separately)

For fear movies, both fear and surprise ratings change based on the colour palette.Figure A 5 and Figure A 6 shows both fear and surprise ratings for the fear movies.

Furthermore, we took the test of repeated measure (within-subject) ANOVA on the click time data with four factors of emotion (4 levels), intensity (2 levels), brush style (2 levels) and colour palette (4 levels). The results did not indicate any main effect of the factors used. Table A 16 contains the results of the ANOVA test. We will discuss the result of all studies and their implications in the next chapter.

5: DISCUSSION, FUTURE WORK, AND APPLICATIONS

In this chapter, we discuss the limitations of the studies and some observations from the studies, followed by the implications for the future work and the anticipated applications of this technique.

5.1 Limitations of the Studies

During the design of the studies, we tried to minimize the factors, which limit the scope of our work. However, to preserve the required validity and reliability, we made some decisions that could induce some limitations to this research.

One of the main limitations of our studies rises from considering only the six basic emotions as the units of our measurements. It is known that each of the six basic emotions represents a family of emotions and there are variations within each family capturing the slightly different qualities of that emotion (Dalgleish & Power, 1999). One anticipated implication of our choice was that we could not fully capture the perceived changes in the quality of the displayed emotions and we think that in some cases, applying a specific colour palette changes not the intensity of the emotion but the quality or flavour of that emotion. On the other hand, there is not a full list of all variations of emotions approved by the majority of researchers. Some previous researchers tried to compile a more comprehensive list (Whissell, 1989a) but the facial configuration for these emotions is highly subjective. We tried to remove these ambiguities from the design of our study by using the six basic expressions.

Another concern was how much the scale of 0-6 can capture the subtle differences in the movies. The results revealed that the used scale was fairly effective for capturing the effects we were looking for. The above-mentioned limitations are closely related to the construct validity of our studies. Construct validity refers to the extent to which operationalizations of a construct actually measure what the theory says it does. In this case the construct that we aimed to measure was the perceived intensity of a basic emotion in a character sequence which the experiment set up sufficiently captured. However, the construct for the bigger question, which incorporates this work as a subset, is the perceived emotion; the current experiment settings lack the adequate construct validity for such a construct.

The timing of the facial expressions poses another limitation on our studies. Ekman and many other researchers have properly identified the importance of the correct timing in the recognition of facial expressions (Darwin, Ekman, & Prodger, 2002; Ekman & Friesen, 2003). In general, the formation of each facial expression involves three stages: onset, duration and offset. The onset refers to the period from the beginning to the formation of the full expression on the face. The duration is the time from the end of onset to the time that the facial expression starts to recede or change to another expression. At last, the offset is the time it takes the facial expression to disappear.

According to Ekman (2003), emotions vary in their timing; for instance, surprise is the briefest expression and it often has a sudden onset. Even the slightly different emotions in one family have different timings. For example, unanticipated fear is brief while the fear of an anticipated event can grow over time. Therefore, the timing of the facial expressions is a clue to spot the potential deception (Ekman & Friesen, 2003). On the other hand, Ekman (2003) states that the timing of facial expressions depends on the social context, which we did not intend to include in our study. Thus, we chose to use the same duration for all the movies. Furthermore, we were reluctant to give the participants any clue that induces the impression of watching only a single facial expression. Using similar timing for all the four expressions let us capture any potential secondary and tertiary emotions introduced by using a colour palette.

In order to improve the internal validity of our studies, we incorporated a number of elements: 1) the first pilot study with the three intensity levels demonstrated the appropriateness of the 0-6 scale in capturing the differences of the three intensity (energy) levels and the users' sensitivity to those intensity levels. 2) The order of watching the movies was randomized for each participant to mitigate the possible carry-over effect from one movie to a subsequent movie. and 3) the subjects responded to each movie three to five times depending on the study which helped in stabilizing their responses relative to the whole set of movies.

External validity determines how much the findings are held true for other cases, times and situations. In other terms, this type of validity is concerned with the generalizability of the results. A major concern in this regard is the selection of the sample group (participants) so that it is a good representative for the population. The subjects of our main studies were from the undergraduate students in the University of British Columbia (UBC) who participated in the study for course credits.

Another concern about the validity of our studies was how much the subjects were aware of the hypothesis and the variables of our study. Since, the main difference among the movies was the colour palettes used, it was possible, especially for the third pilot study and the final study, that the subjects' responses were affected by guessing the hypothesis of the study; a phenomenon that is known as the experimenter's demand in experimental psychology. We identified this issue during the informal chats with some subjects about the third pilot study. In order to eliminate the issue for the final study, we added more variations to the movies, told the subjects about having other settle variations in the movies, and asked them to respond based on their impressions. The variations in the patterns of the results imply that the choices correspond to users' personal impression of each movie.

Furthermore, using just one head model in our experiments threatens the external validity of our research. However, we tried to choose a general head model that does not exhibit specific characteristics in order to eliminate this factor. Follow up studies with one or more head models would strengthen the external validity of this work.

Finally, we tried to eliminate any specific characteristics such as particular movements or audio from the character sequences used. Each of these sequences can be incorporated into a longer animation sequence and we anticipate that the emotional impacts of these sequences would be similar when viewed individually or incorporated into a longer character sequence. Nevertheless, we intend to study the application of the results from these studies on a longer animated sequence in order to determine the scope of application for these studies.

5.2 Discussion

In brief, we conducted a series of user studies to investigate the effect of colour palette and to a less extent texture on the users' perception of an emotion in an animated character sequence. The first two main studies while suggested some trends on specific emotions, could not fully capture the effect of the chosen palettes. Although artists use warm and cool tones, we believe the result of separating the colour space into the warm and cool palettes is not fine-grained or primary enough for finding the affective response to an emotional sequence in a controlled experiment. In the case of the second study, the grouping effect also confounded the results. Finally, the results of the last pilot study and the final study with the redesigned colour palettes confirmed our hypothesis, which suggests that there are certain colours that enhance or weaken the emotions perceived in an emotional character sequence. For the last pilot study, the ratings for all the four emotions (anger, joy, fear and surprise) followed the hypothesis for the effect of the congruent vs. the incongruent palettes although for surprise, the original colour palette had the highest rating, which was not hypothesized.

Working with not single colours but ranges of colours across a 3D model, along with complications of animated movement (compared to stills) makes for a daunting task of getting repeatable and understandable measure results. We believe there are too many variables at play for the loose and complicated space of perceived emotions on a colour and texture manipulated animated face. Once these issues became apparent in the early studies, we tried to align all the variables with known previous data in the emotion and colour space. In later studies, we carefully aligned the facial configurations on the 3D face to the Ekman's facial expression examples. Also, for the last study, we adjusted the colour palettes more towards the average colours suggested by da Pos and Green-Armytage(2007). According to the results, the congruent colours for the anger and joy sequences elevated the intensity of the emotion perceived, while for surprise and fear we did not get such an effect.

We can anticipate two reasons for the unexpected trend in the ratings of the fear movies: 1) The colour combinations provided in da Pos and Green-Armytage's paper (2007) are more varied for the fear emotion compared to the more consistent colour associations for anger, joy, and even surprise. Thus, one might conclude that people have different opinions about the congruent colour for the fear emotion. However, a specific trend is observable in the ratings of the fear movies in our study, with the highest rating for the original palette, followed by the incongruent and congruent palettes. This indicates that the subjects in our study had certain colour preferences for the fear expression, which leads us to the second reason. 2) The colour palettes that we used might not be suitable for heightening the effect of the fear and surprise movies because of the hue, saturation, or brightness values chosen. As mentioned before, the noticeable differences in the ratings for the original, congruent and incongruent palettes for the fear movies support this explanation.

Furthermore, the constant pattern in the ratings for the surprise movies was not anticipated in our hypothesis. A possible explanation for such pattern can be the differences between the facial configuration chosen for the surprise in our studies and the study by da Pos and Green-Armytage (2007), although both facial configurations are based on the Ekman's book (2003). While the surprise in da Pos and Green-Armytage's paper (2007) displays a joyful or pleasant surprise, the surprise in our movies was more of a shocked or unpleasant surprise. The similarity between the colour combinations chosen for the joy and surprise movies in da Pos and Green-Armytage's study (2007) can also be due to the pleasant surprise chosen in that study.

These results suggest that colours and emotions are more complicated than first assumed. These studies give evidences and guidelines for further studies to develop a model for the association between colours and emotions.

In addition, in this study, the energy effects for all the emotions are in the 1-1.5 range. For the congruency factor, in the significant cases that follow our hypothesis such as anger and joy, the effect is around 0.25-0.5. The perceived effect is the highest for the anger movies with a difference of 0.6 in the mean ratings. For the joy movies, this difference decreases to 0.2. These values are not particularly high on a 0-6 scale, which raises the issue of the practical significance of the findings. However, compared to the energy effect, the effect for the congruency factor seems reasonable. Furthermore, we believe that the controlled settings of the experiment might have reduced the effects perceived and such effects can vary in a gaming/animation context with other emotional factors involved. Thus, another study on a longer sequence with more emotional context could better examine the practical significance of the proposed technique.

Based on the results of the studies, one can define knowledge-based painterly rendering as an informed painterly rendering technique, which utilizes the knowledge about the scene and its emotional content together with the knowledge of the painterly techniques and their affective content in order to make more expressive animated sequences.

5.3 Future Work

We anticipated a number of extensions to this work, one of which is applying the correct timing to each of the facial expression sequences. This would help the viewer in the recognition of the facial expressions. However, as mentioned in section 5.1, it might lead to the confounded results for the study. Thus, this modification should be accompanied with appropriate considerations in order to avoid imposing one facial expression on the viewer.

Similar studies could examine the other facial expressions such as sadness, and disgust or even a longer list of the facial expressions, using the appropriate colour palettes. As mentioned before, one of the limitations of this study was considering only the six basic expressions. While this method of measurement helped in limiting the scope of the study and avoids the inclusion of many undesired factors in the results, we could not fully capture the other possible effects of the colour on the quality of the emotions. We think that colours could also cause a slight variation in the type of the emotion. In another words, colours can change the emotion perceived to a nearby emotion in the same family of emotions (see Ekman's description of the emotion families (1992)). Thus, repeating the study with other measurements that better capture the quality of the emotions is very beneficial.

In addition, conducting the same study on the perception of the personality is another interesting area to follow. For example, the warm-light colour palette can increase the ratings on the affiliation axis while the warm-dark palette can change the perceived dominance in the animated character. Building on the results of this study, the affective content of the other parameters such as shadows in a painterly rendering could be examined in the follow-up studies. Such studies give a broader view on the implications of using these techniques in the gaming and animation industries.

Lastly, the affective impact of using different textures on the viewer's perception needs to be investigated in more detail. Similar affective studies for other sequences and scenes such as still life, and landscape also illuminate the promise of the painterly style for other types of sequences.

5.4 Applications of the Work

Usually the animation and movie industries use a variety of techniques such as lighting and music to boost or flavour the emotional impact of a scene. The impact of music on emotions has been subject of many studies. An exemplary feature of a soundtrack, which corresponds to emotions, is tempo. Music with fast tempo induces excitement while a slow tempo conveys calmness or sadness (Juslin & Sloboda, 2001). Movie/animation sequences usually require carefully composed soundtracks to involve viewers in the story effectively (A. J. Cohen, 2001). Lighting is another effective tool for adding meaning and emotion to characters and scenes (de Melo & Paiva, 2007). The number, colour, direction, and the quality of a scene's lightings has a direct impact on how the characters and scenes are perceived and consequently on the viewers' emotional gain from the movie/animation sequence. As an example, well-lighted scenes induce a pleasant mood while dark scenes are usually associated with sadness and mystery (Birn, 2005). These techniques have been used for many years as effective tools for adding to the emotional impact of movie/animation sequences. We believe that the proposed technique provides the animators with an additional tool to augment/flavour the emotional content of a scene. As mentioned in section 2.3.3, the visual style of a scene plays an important role on the viewers' impression about that scene. Past studies on the affective content of colours and lines have tried to capture the emotional effect of basic depiction elements in a NPR image. The effectiveness of using the painterly rendering on character sequences relies on the ability of the depiction system in adding emotional content to a scene or sequence. In this series of studies, we explored the area of painterly rendering for such emotional effects and examined the effect of the colour palettes and to a less extent texture on users' feelings about a painterly facial character sequence. Based on the results of the studies, we believe that painterly depiction can serve as an additional technique to augment the emotional content of character sequences, similar to music and lighting techniques.

In addition, since the proposed technique modifies the visual aspect of the scene in the final stage of the production, it can accompany almost any other method/algorithm to achieve higher quality for the animated sequence. We are collaborating with a pre-visualization company to apply this method to some of their sequences. Previsualization is a technique for visualizing the scenes of a movie with quickly created animation sequences before filming starts. Previsualization technique helps the director choose the appropriate staging parameters (e.g. lighting, camera settings) for the actual filming. The proposed technique in this thesis will provide the company with the ability to show various visual styles for a sequence to their clients and identify the desired settings for the clients.

Since the proposed technique enhances the expressiveness of an emotional character sequence by changing its visual style, another anticipated application area for this technique is automatically or rapidly generated character sequences. These sequences usually lack expressiveness, which reduces the emotional quality of the work and diminishes the viewer's engagement. To overcome this issue, past researchers have proposed different methods for adding expressiveness to facial and body movements in character sequences. However, most of the proposed approaches are processing intensive, depend on a good database of facial/body movements, or need considerable manual tunings by the animator. In contrast, the proposed technique in this thesis requires very little or no manual work by the animator/user. An animator/user can use the proposed settings based on the conducted user studies or explicitly set the painting parameters for the key frames. In either case, the results of the studies can inform the user in selecting the appropriate parameter values for the desired emotional effect in an emotional character sequence. Requiring little manual settings makes this method suitable for the automatically or rapidly generated character sequences and provides an efficient way for achieving better visual results in those sequences. Some of the anticipated applications for this technique are games, short movies and commercials.

Moreover, we believe that using painterly depiction techniques for facial character sequences improves expressiveness with regard to another aspect as well. The phenomenon of the uncanny valley of the human believability is well-known to the face researchers (Parke & Waters, 2008). While many games/animations try to achieve higher expressiveness by adding to the reality of faces, this makes people notice even the slight flaws in the created faces. Moving to a completely synthetic painted world mitigates this issue and is less processing intensive compared to the algorithms used for the highly realistic outputs.

Last but not the least, as identified by Halper et al. (2003), having knowledge about the affective content of the NPR elements not only has advantages for the gaming/animation industry and any other application areas of the NPR systems, but also provides psychologists with a better picture of the human cognitive processes.

APPENDICES

Appendix A: Additional Tables and Charts

A1. Pilot Study 1:

Table A 1- Mauchly's test of sphericity for the first pilot study

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[a]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
emotion	.446	7.273	2	.026	.643	.697	.500
intensity	.414	7.931	2	.019	.631	.679	.500
emotion * intensity	.316	9.685	9	.386	.640	.880	.250

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b. Design: Intercept

Within Subjects Design: emotion + intensity + emotion * intensity

Table A 2- Results of repeated measure (within subject) ANOVA test for the first pilot study

Source		df	Mean Square	F	Sig.	Partial Eta Squared	Observed Power[a]
emotion	Greenhouse-Geisser	1.287	14.992	5.186	.033	.341	.617
Error(emotion)	Greenhouse-Geisser	12.867	2.891				
intensity	Greenhouse-Geisser	1.261	105.795	104.142	.000	.912	1.000
Error(intensity)	Greenhouse-Geisser	12.613	1.016				
emotion * intensity	Sphericity Assumed	4	1.699	3.093	.026	.236	.762

Error(emotion*intensity)	Sphericity Assumed	40	.549				

a. Computed using alpha = .05

Table A 3- Estimated mean for the first pilot study

intensity	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	4.758	.194	4.325	5.191
2	3.103	.182	2.697	3.509
3	1.927	.202	1.478	2.376

Table A 4- Bonferroni's posthoc test on the three intensity levels for the first pilot study

Pairwise Comparisons

(I) intensity	(J) intensity	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	1.655*	.186	.000	1.122	2.188
	3	2.830*	.258	.000	2.090	3.570
2	1	-1.655*	.186	.000	-2.188	-1.122
	3	1.176*	.125	.000	.818	1.534
3	1	-2.830*	.258	.000	-3.570	-2.090
	2	-1.176*	.125	.000	-1.534	-.818

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

A2. Pilot Study 2:

Table A 5- Mean and standard deviation for the second pilot study

Column1	Mean	standard dev.
User1-0	0.730469	1.395233263
User1-1	0.765625	1.436140662
User1-2	0.9375	1.732050808

User1-4	0.902344	1.63845766
User1-5	0.65625	1.167786577
User1-6	0.691406	1.221733089
User1-7	0.976563	1.611063922
User1-8	0.855469	1.497255455
User4-0	0.675781	1.274316185
User4-0	0.722656	1.309555521
User4-1	0.949219	1.589598351
User4-2	0.941406	1.680477399
User4-3	0.8125	1.410047976
User4-4	0.847656	1.44311563
User4-5	0.976563	1.586535719
User4-6	1.078125	1.791524162

A3. Main Study 1:

Table A 6-Mauchly's Test of Sphericity for the first main study

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[a]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
emotion	.380	20.062	5	.001	.621	.676	.333
intensity	1.000	.000	0	.	1.000	1.000	1.000
colourpalette	.675	8.158	5	.148	.778	.875	.333
emotion * intensity	.627	9.659	5	.086	.801	.906	.333
emotion * colourpalette	.170	33.322	44	.890	.738	1.000	.111
intensity * colourpalette	.738	6.303	5	.278	.854	.976	.333
emotion * intensity * colourpalette	.068	50.521	44	.253	.639	.890	.111

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b. Design: Intercept

Within Subjects Design: emotion + intensity + colourpalette + emotion * intensity + emotion * colourpalette + intensity * colourpalette + emotion * intensity * colourpalette

Table A 7-Estimated mean for the four colour palettes in the first main study

colourpalette	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	2.855	.129	2.588	3.123
2	2.591	.162	2.255	2.928
3	2.636	.147	2.331	2.940
4	2.850	.154	2.531	3.169

Table A 8-Estimated means for the emotion*congruency interaction in the first study

6. emotion * colourpalette

Measure:MEASURE_1

emotion	colourpalette	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
1	1	3.061	.153	2.743	3.378
	2	2.970	.209	2.537	3.402
	3	2.883	.187	2.495	3.271
	4	2.926	.184	2.545	3.308
2	1	1.652	.206	1.226	2.079
	2	1.548	.256	1.017	2.078
	3	1.587	.216	1.139	2.035
	4	1.600	.239	1.104	2.096
3	1	3.287	.189	2.896	3.678
	2	2.913	.207	2.484	3.342
	3	3.048	.203	2.627	3.469
	4	3.574	.207	3.145	4.002
4	1	3.422	.198	3.011	3.832
	2	2.935	.228	2.461	3.409
	3	3.026	.193	2.626	3.426
	4	3.300	.176	2.935	3.665

A4. Joy Analysis for Main Study 1:

Table A 9-Mauchly's test of sphericity for the joy movies in the first main study

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[a]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
intensity	1.000	.000	0	.	1.000	1.000	1.000
colourpalette	.716	6.918	5	.227	.840	.958	.333
intensity * colourpalette	.931	1.492	5	.914	.958	1.000	.333

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b. Design: Intercept

Within Subjects Design: intensity + colourpalette + intensity * colourpalette

Table A 10-Estimated mean for the four colour palettes in the first main study

colourpalette	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	3.287	.189	2.896	3.678
2	2.913	.207	2.484	3.342
3	3.048	.203	2.627	3.469
4	3.574	.207	3.145	4.002

Table A 11- Bonferroni's posthoc test for the four palettes of the joy movies in the first main study

(I) colourpalette	(J) colourpalette	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	.374*	.125	.039	.013	.735
	3	.239	.130	.483	-.139	.617
	4	-.287*	.090	.026	-.549	-.025
2	1	-.374*	.125	.039	-.735	-.013
	3	-.135	.129	1.000	-.509	.239
	4	-.661*	.134	.000	-1.050	-.271
3	1	-.239	.130	.483	-.617	.139
	2	.135	.129	1.000	-.239	.509

	4	-.526*	.149	.011	-.957	-.095
4	1	.287*	.090	.026	.025	.549
	2	.661*	.134	.000	.271	1.050
	3	.526*	.149	.011	.095	.957

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

A5. Main Study 2:

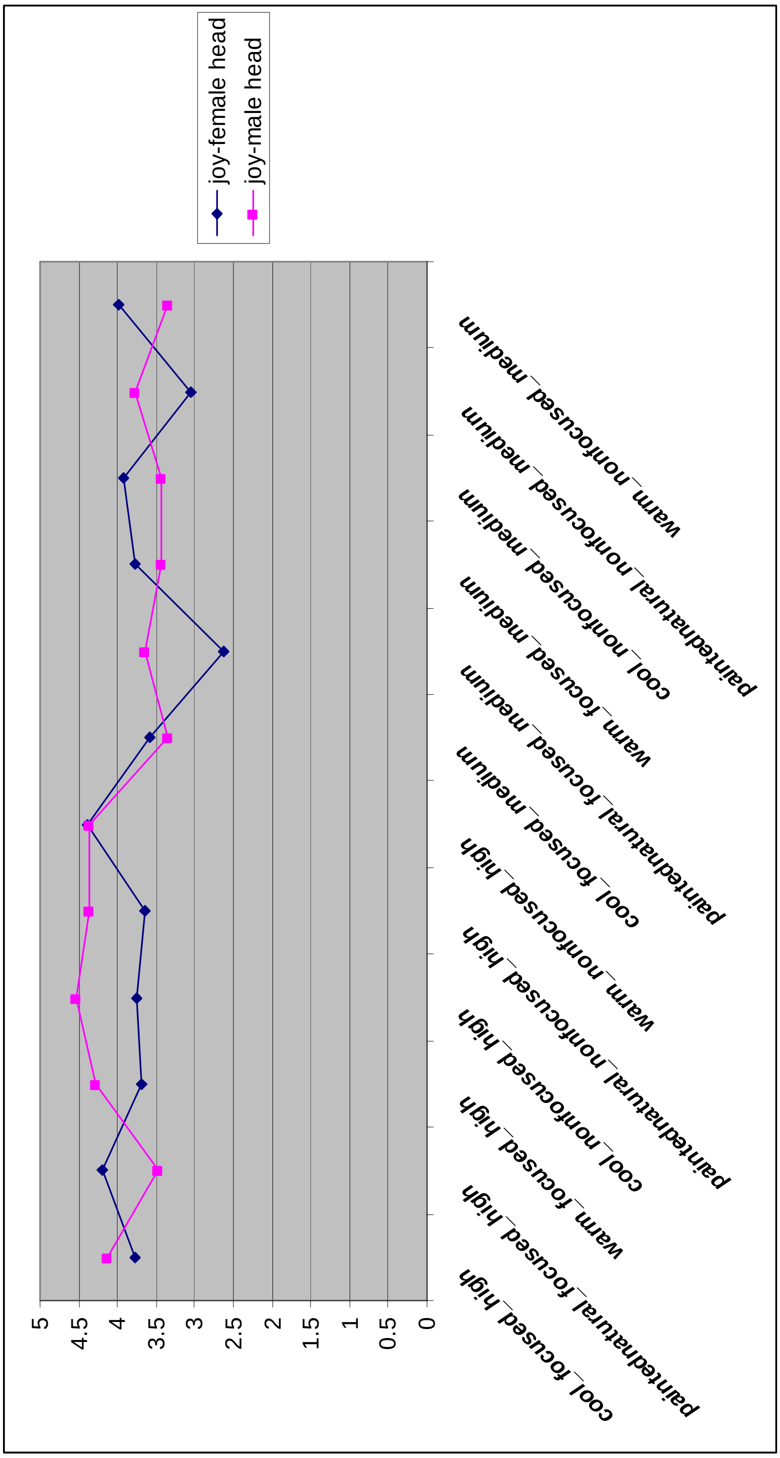

Figure A 1- Ratings for the joy movies on the female and male head models

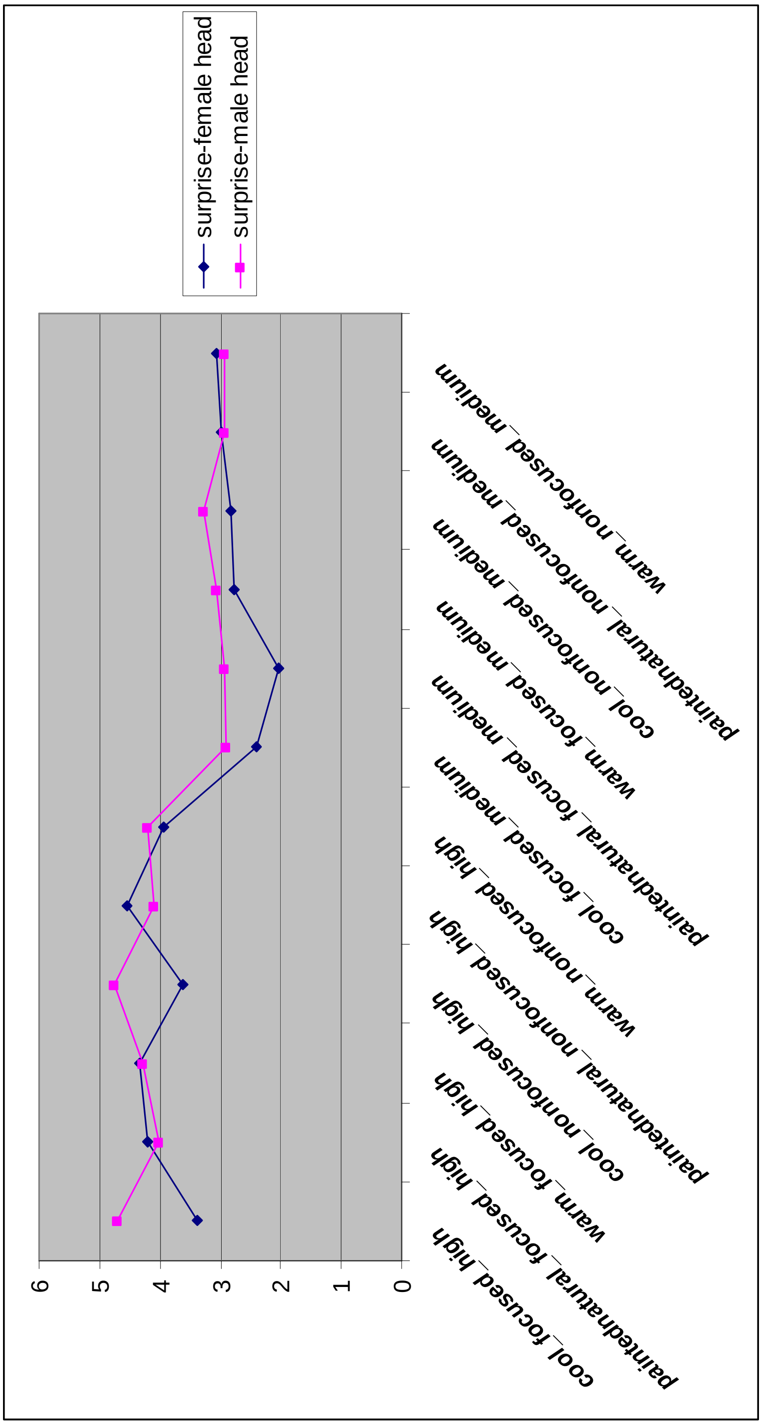

Figure A 2- Ratings for the surprise movies on the female and male head models

A6. Pilot Study 3:

Table A 12- Mauchly's test of sphericity for the third pilot study

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[a]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
emotion	.208	19.979	5	.001	.677	.793	.333
energy	1.000	.000	0	.	1.000	1.000	1.000
congruency	.997	.043	2	.979	.997	1.000	.500
emotion * energy	.512	8.521	5	.131	.754	.907	.333
emotion * congruency	.092	28.113	20	.118	.597	.827	.167
energy * congruency	.645	5.703	2	.058	.738	.804	.500
emotion * energy * congruency	.115	25.452	20	.199	.668	.969	.167

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b. Design: Intercept

Within Subjects Design: emotion + energy + congruency + emotion * energy + emotion * congruency + energy * congruency + emotion * energy * congruency

Table A 13- Estimated mean for the original, incongruent, and congruent palettes in the third pilot study

congruency	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	3.475	.205	3.035	3.915
2	3.240	.177	2.860	3.619
3	3.744	.187	3.344	4.144

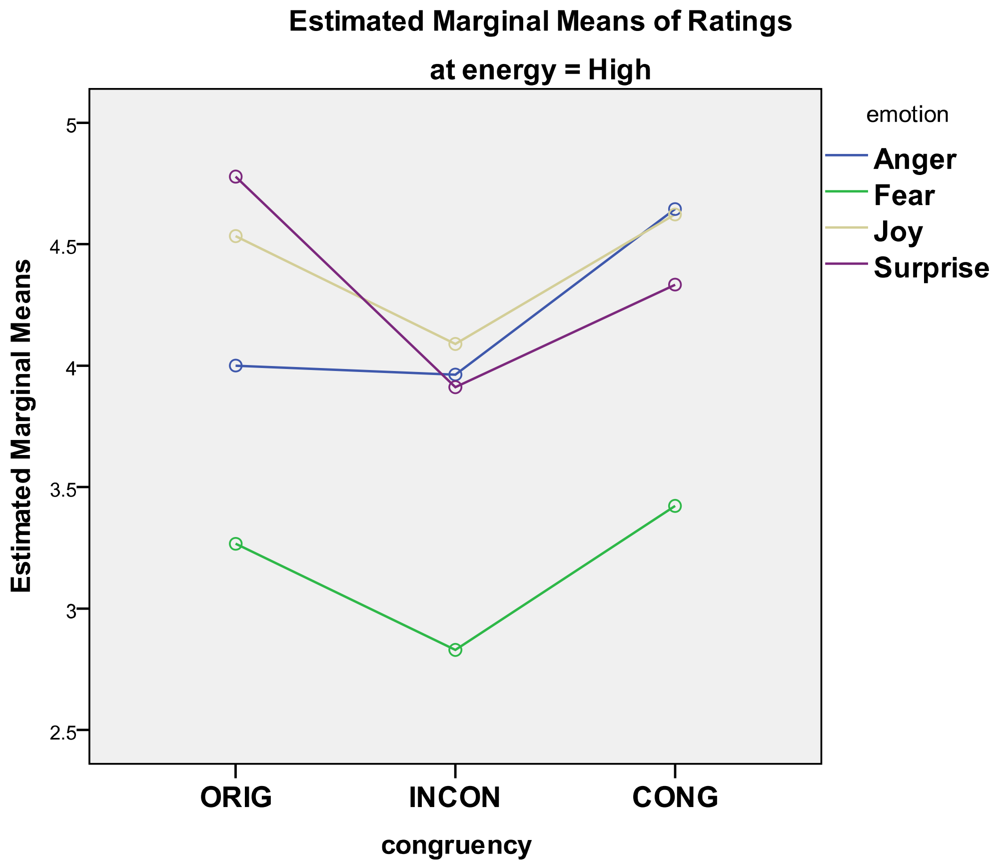

Figure A 3 - Ratings for CONG/INCON/ORIG palettes in the high intensity (energy)

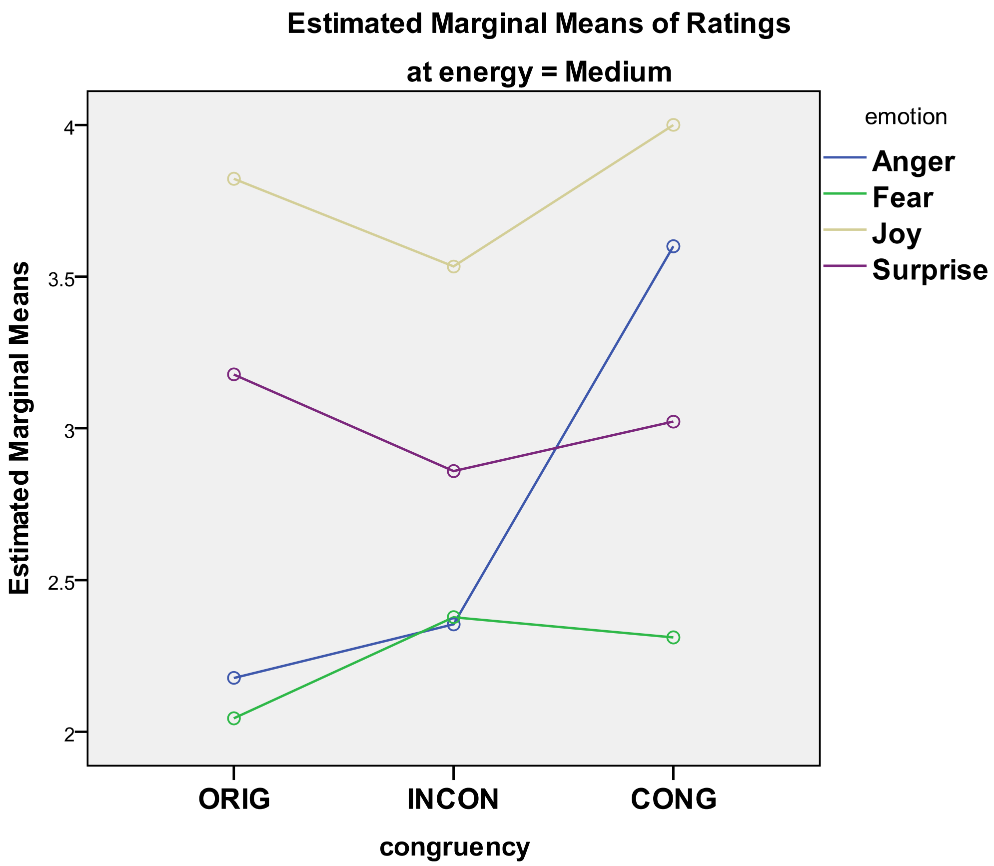

Figure A 4- Ratings for CONG/INCON/ORIG palettes in the medium intensity (energy)

A7. Final Study:

Table A 14- Mauchly's test of sphericity for the final study

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[a]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Emotion	.876	2.608	5	.760	.921	1.000	.333
Energy	1.000	.000	0	.	1.000	1.000	1.000
Brushstyle	1.000	.000	0	.	1.000	1.000	1.000
Congruency	.888	2.374	2	.305	.899	.978	.500
emotion * energy	.812	4.097	5	.536	.895	1.000	.333
emotion * brushstyle	.794	4.561	5	.472	.869	1.000	.333
energy * brushstyle	1.000	.000	0	.	1.000	1.000	1.000
emotion * energy * brushstyle	.742	5.891	5	.317	.861	.992	.333
emotion * congruency	.229	27.647	20	.123	.711	.914	.167
energy * congruency	.758	5.550	2	.062	.805	.862	.500
emotion * energy * congruency	.431	15.784	20	.735	.787	1.000	.167
brushstyle * congruency	.869	2.805	2	.246	.884	.960	.500
emotion * brushstyle * congruency	.159	34.562	20	.024	.702	.900	.167
energy * brushstyle * congruency	.876	2.643	2	.267	.890	.967	.500
emotion * energy * brushstyle * congruency	.313	21.783	20	.359	.724	.936	.167

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b. Design: Intercept

Within Subjects Design: emotion + energy + brushstyle + congruency + emotion * energy + emotion * brushstyle + energy * brushstyle + emotion * energy * brushstyle + emotion * congruency + energy * congruency + emotion * energy * congruency + brushstyle * congruency + emotion * brushstyle * congruency + energy * brushstyle * congruency + emotion * energy * brushstyle * congruency

Table A 15- Estimated means for the emotion*congruency interaction in the final study

emotion * congruency

Emotion	congruency	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
1	1	2.629	.232	2.145	3.112
	2	2.534	.215	2.087	2.981
	3	3.125	.246	2.613	3.637
2	1	2.360	.153	2.041	2.679
	2	2.036	.177	1.667	2.405
	3	1.780	.238	1.285	2.276
3	1	3.557	.216	3.107	4.007
	2	3.661	.217	3.210	4.112
	3	3.852	.172	3.495	4.210
4	1	3.659	.205	3.233	4.085
	2	3.703	.192	3.303	4.102
	3	3.674	.151	3.360	3.988

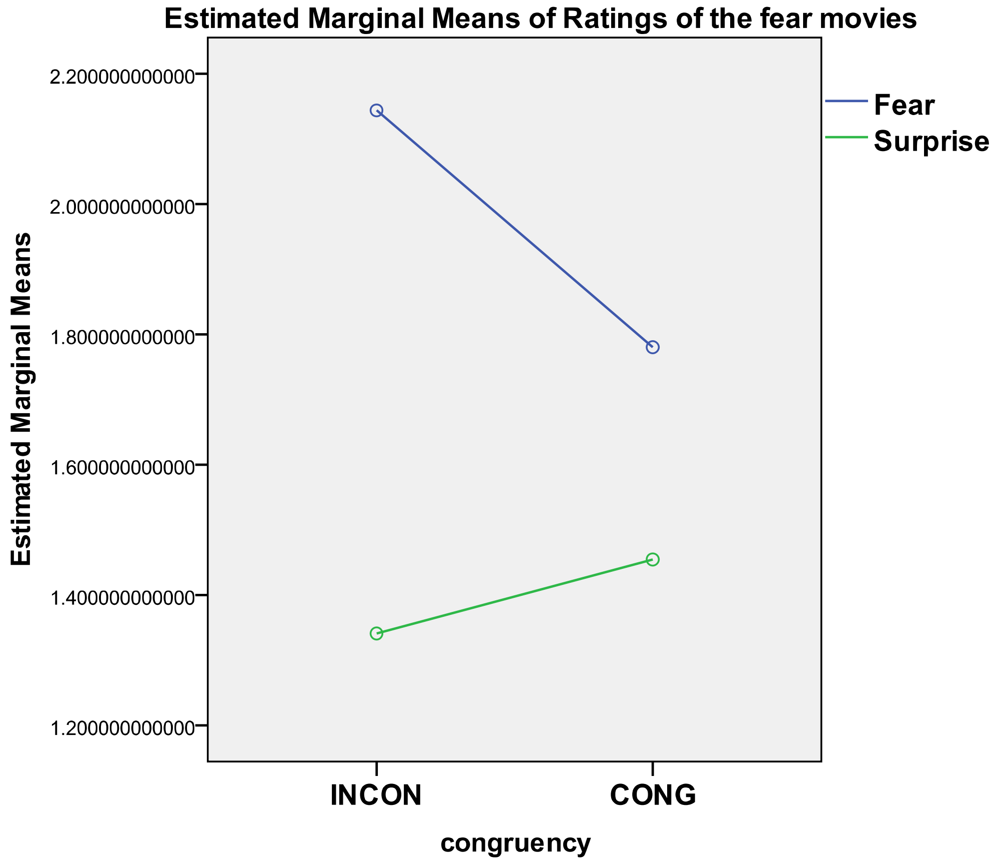

Figure A 5- Fear and surprise ratings for the fear movies (averaged over the two intensity levels)

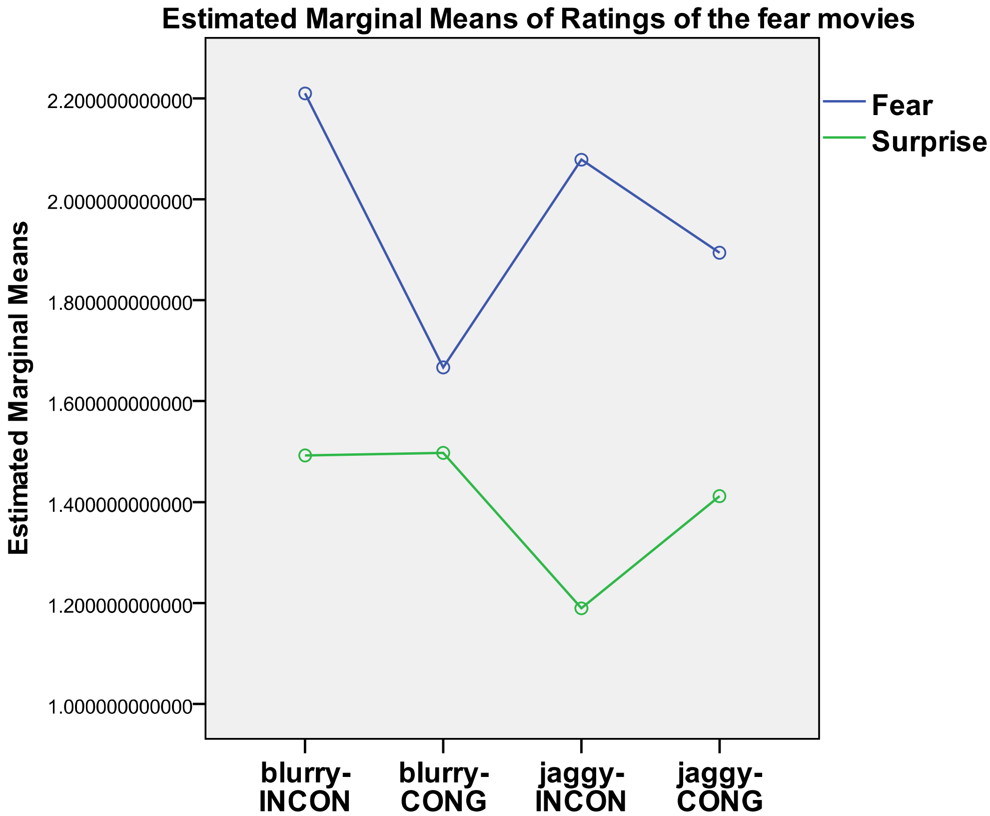

Figure A 6- Fear and surprise ratings for the fear movies (showing the two brush styles separately)

Table A 16- Results of repeated measure (within-subject) ANOVA test on click time data in the final study

Source		df	Mean Square	F	Sig.	Partial Eta Squared	Observed Power[a]
Emotion	Greenhouse-Geisser	1.663	1.036	.554	.548	.026	.127
Error(emotion)	Greenhouse-Geisser	34.913	1.869				
Intensity	Sphericity Assumed	1	.002	.003	.958	.000	.050

Error(intensity)	Sphericity Assumed	21	.774				
Brushstyle	Sphericity Assumed	1	.389	.936	.344	.043	.152
Error(brushstyle)	Sphericity Assumed	21	.416				
colourpalette	Greenhouse-Geisser	1.475	1.688	.797	.425	.037	.157
Error(colourpalette)	Greenhouse-Geisser	30.966	2.119				
emotion * intensity	Greenhouse-Geisser	2.213	.752	.795	.469	.036	.184
Error(emotion*intensity)	Greenhouse-Geisser	46.463	.946				
emotion * brushstyle	Sphericity Assumed	3	.946	1.948	.131	.085	.479
Error(emotion*brushstyle)	Sphericity Assumed	63	.486				
intensity * brushstyle	Sphericity Assumed	1	.030	.050	.826	.002	.055
Error(intensity*brushstyle)	Sphericity Assumed	21	.610				
emotion * intensity * brushstyle	Sphericity Assumed	3	.405	.972	.412	.044	.253
Error(emotion*intensity*brushstyle)	Sphericity Assumed	63	.417				
emotion * colourpalette	Greenhouse-Geisser	4.009	.902	.638	.637	.029	.201
Error(emotion*colourpalette)	Greenhouse-Geisser	84.185	1.415				
intensity * colourpalette	Greenhouse-Geisser	2.546	.126	.162	.896	.008	.076
Error(intensity*colourpalette)	Greenhouse-Geisser	53.463	.776				

emotion * intensity * colourpalette	Greenhouse-Geisser	3.312	1.864	.964	.421	.044	.265
Error(emotion*intensity*colourpalette)	Greenhouse-Geisser	69.549	1.933				
brushstyle * colourpalette	Greenhouse-Geisser	1.996	1.641	1.827	.174	.080	.359
Error(brushstyle*colourpalette)	Greenhouse-Geisser	41.919	.898				
emotion * brushstyle * colourpalette	Greenhouse-Geisser	4.955	.474	.461	.803	.021	.168
Error(emotion*brushstyle*colourpalette)	Greenhouse-Geisser	104.045	1.029				
intensity * brushstyle * colourpalette	Greenhouse-Geisser	1.914	.677	1.016	.368	.046	.211
Error(intensity*brushstyle*colourpalette)	Greenhouse-Geisser	40.202	.666				
emotion * intensity * brushstyle * colourpalette	Greenhouse-Geisser	5.467	.881	1.185	.320	.053	.429
Error(emotion*intensity*brushstyle*colourpalette)	Greenhouse-Geisser	114.816	.743				

a. Computed using alpha = .05

Appendix B: Face Parameter Standards

Table B 1-List of the Action units defined in the FACS

AU number	AU name
0	Neutral face
1	Inner Brow Raiser -- Frontalis (pars medialis)
2	Outer Brow Raiser -- Frontalis (pars lateralis)
4	Brow Lowerer -- Depressor glabellae, Depressor supercilii, Corrugator supercilii
5	Upper Lid Raiser -- Levator palpebrae superioris
6	Cheek Raiser -- Orbicularis oculi (pars orbitalis)
7	Lid Tightener -- Orbicularis oculi (pars palpebralis)
9	Nose Wrinkler -- Levator labii superioris alaeque nasi
10	Upper Lip Raiser -- Levator labii superioris, caput infraorbitalis
11	Nasolabial Deepener -- Zygomaticus minor
12	Lip Corner Puller -- Zygomaticus major
13	Sharp Lip Puller -- Levator anguli oris (also known as Caninus)
14	Dimpler -- Buccinator
15	Lip Corner Depressor -- Depressor anguli oris (also known as Triangularis)
16	Lower Lip Depressor -- Depressor labii inferioris
17	Chin Raiser -- Mentalis
18	Lip Pucker -- Incisivii labii superioris and Incisivii labii inferioris
19	Tongue Out
20	Lip stretcher -- Risorius w/ platysma
21	Neck Tightener -- Platysma
22	Lip Funneler -- Orbicularis oris
23	Lip Tightener -- Orbicularis oris
24	Lip Pressor -- Orbicularis oris
25	Lips part -- Depressor labii inferioris or relaxation of Mentalis, or Orbicularis oris
26	Jaw Drop -- Masseter, relaxed Temporalis and internal pterygoid
27	Mouth Stretch -- Pterygoids, Digastric
28	Lip Suck -- Orbicularis oris
29	Jaw Thrust

30	Jaw Sideways
31	Jaw Clencher -- Masseter
32	Lip Bite
33	Cheek Blow
34	Cheek Puff
35	Cheek Suck
36	Tongue Bulge
37	Lip Wipe
38	Nostril Dilator
39	Nostril Compressor
41	Lid Droop
42	Slit
43	Eyes Closed -- Relaxation of Levator palpebrae superioris; Orbicularis oculi (pars palpebralis)
44	Squint
45	Blink -- Relaxation of Levator palpebrae superioris; Orbicularis oculi (pars palpebralis)
46	Wink -- Relaxation of Levator palpebrae superioris; Orbicularis oculi (pars palpebralis)

Table B 2- Action Units involved in the six basic expressions

Basic Facial Expression	**Involved Action Units**
Anger	AU2, 4, 7, 9, 10, 20, 26
Happiness	AU1, 6, 12, 14
Sadness	AU1, 4, 15, 23
Surprise	AU1, 2, 5, 15, 16, 20, 26
Fear	AU1, 2, 5, 15, 20, 26
Disgust	AU9, 10

Appendix C: Electronic Files

Electronic data and files listed below and appended as supplemental files or as a CD or DVD, form part of this work under the copyright of this author.

Folder “Movies for the studies” contains the movie and image files for all the studies (six folders). The Movie files were created in Adobe Premier CS3. They are .mov files and can be opened in Quicktime player or any other player supporting .mov format. Images are .JPG files and can be viewed in any picture viewer program. 916MB

Folder “Keyframe files for the facial sequences” contains .kyf files, which are the keyframe animation sequences created in and can be opened by the iFace program. 56KB

Folder “Apparatus for the studies” contains the apparatus for the studies. This program can only run on the Windows operating system. Windows Seven, Vista and older is supported; but the program was not tested on later versions of Windows. “list of files in this folder.txt” contains all necessary information and files to set up the apparatus.

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