Investigating Macro- and Microexpressions in Computer Graphics Animated Faces

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Due to varied personal, social or even cultural situations, people sometimes conceal or mask their true emotion. These suppressed emotions can be expressed in a very subtle way by brief movements called microexpressions. We investigate human subjects' perception of hidden emotions in virtual faces, inspired by recent psychological experiments. We created animations with virtual faces showing some facial expressions and inserted brief secondary expressions in some sequences, in order to try to convey a subtle second emotion in the character. Our evaluation methodology consists of two sets of experiments, with three different sets of questions. The first experiment verifies that the accuracy and concordance of the participant's responses with synthetic faces matches the empirical results done with photos of real people in (Shen, Wu, & Fu, 2012). The second experiment verifies if participants could perceive and identify primary and secondary emotions in virtual faces. The third tries to evaluate the participant's perception of realism, deceit and valence of the emotions. Our results show that most of the participants recognized the foreground (macro) emotion and most of the time they had perceived the presence of the second (micro) emotion in the animations, although they did not identify it correctly in some samples. This experiment exposes the benefits of conveying microexpressions in Computer Graphics characters, as they may visually enhance a character's emotional "depth" through subliminal microexpression cues and consequently increase its perceived social complexity and believability.

Introduction

Faces can be considered the center of human communication. In addition to supporting verbal communication, the face is responsible for the transmission of many nonverbal signals that complement and complete verbal expression. Humans have been born programmed to look for and recognize faces (Johnson & Morton, 1991) and there are several studies on facial expressions that suggest they are universal and a physiological response to our emotions (Darwin, 1872; Ekman, 1971). However, due to varied personal, social or even cultural situations, people sometimes are led to conceal or mask their true emotions. These suppressed emotions may be expressed in the form of *microexpressions*, which are very brief facial expressions that occur when a person either deliberately or unconsciously conceals an emotion being felt (Ekman & Friesen, 1969).

According to Ekman (Ekman & Friesen, 1969; Ekman, 2009), a microexpression can express one of the universally recognized emotions (disgust, anger, fear, sadness, happiness, surprise, and more recently he included contempt) and since it occurs very quickly (1/25*th* to 1/15*th* of a second) it may be missed by some people, but detected by a skilled observer. Currently, microexpressions have been investigated mostly in the context of lying and deception detection (Matsumoto & Hwang, 2011; Porter & ten Brinke, 2008, 2010; Vrij, Granhag, & Porter, 2010). Other studies investigate the human capability to perceive, consciously or unconsciously, microexpressions and the role they play in communication and human behavior (Bornemann, Winkielman, & van der Meer, 2011; Shen et al., 2012; W. Li, Zinbarg, Boehm, & Paller, 2008).

It is still a challenge to reflect all these complex facial behaviors in computer animated faces. Although there have been great advances in modeling, rigging, rendering, motion capture and retargeting techniques – with the goal of escaping the "Uncanny Valley" (Alexander, Rogers, Lambeth, Chiang, & Debevec, 2009; McDonnell, Breidt, & Bülthoff, 2012) – the creation of realistic and convincing face behaviors for games and movies is still strongly dependent on animator skills. There are some studies about how to convey and evaluate a character's complex facial behaviors (Paleari & Lisetti, 2006; Bevacqua, Mancini, Niewiadomski, & Pelachaud, 2007; Rehm, 2008; Orvalho & Sousa, 2009; Niewiadomski, Hyniewska, & Pelachaud, 2009; Queiroz, Braun, et al., 2010; Demeure, Niewiadomski, & Pelachaud, 2011; de Melo, Carnevale, & Gratch, 2011; Xolocotzin Eligio, Ainsworth, & Crook, 2012), but few really focus on microexpressions (Zielke, Dufour, & Hardee, 2011).

In this context, this paper explores users' perception of hidden emotions in virtual faces, inspired by recent psychological experiments (Bornemann et al., 2011; Shen et al., 2012). We investigate the hypothesis that facial microexpressions (at some subliminal presentation level) can subtly suggest a second emotion to a user even when embedded in a neutral or conflicting facial expression. This both mirrors human perceptual experiments and demonstrates a simple mechanism for conveying a repressed or alternative emotion on an animated character's face. We expect that, if we convey microexpressions even in a subtle (yet simple) way in the animation, we will create expressive richness for a viewer or VR (Virtual Reality) participant because the animated character can possess two emotional streams: e.g., one based on interaction with the subject and the other based on its own internal state, situation or perceptions in the VR.

In order to investigate our hypothesis, we undertook an experiment with subjects, in which some brief facial expression videos were presented and participants were asked which emotion (or emotions) they perceived. This experiment was inspired by psychological experiments; the main differences of our approach were the use of *animated* virtual faces instead of real human photographs and the use of *animated* expressions instead of just switching between the photographs. We can then evaluate the subjects' perceptions regarding the presence and identity of any animated microexpressions.

This paper is organized as follows: the next section presents some foundational work upon which we based our own experiments and reviews methods used to generate complex facial behaviors. Then, we present our methodology of computer-based animated experiments. Finally we discuss the experimental results and point to future applications.

Related Work

The existence of microexpressions was first reported by Haggard and Isaacs (Haggard & Isaacs, 1966) where they were initially called "micromomentary expressions". They were formally named microexpressions by Ekman (Ekman & Friesen, 1969) and presently there is great interest in this subject in research projects related to lying and deception detection (Ekman, 2009; Matsumoto & Hwang, 2011; Porter & ten Brinke, 2008, 2010; Vrij et al., 2010). There are also works using computer vision techniques and learning algorithms to automatically recognize microexpressions in video sequences (Metaxas & Zhang, 2013; Michael, Dilsizian, Metaxas, & Burgoon, 2010; Pfister, Li, Zhao, & Pietikainen, 2011; Shreve, Godavarthy, Goldgof, & Sarkar, 2011; Wu, Shen, & Fu, 2011). Recently databases have been created (Yan, Wu, Liu, Wang, & Fu, 2013; X. Li, Pfister, Huang, Zhao, & Pietikainen, 2013) to serve as benchmarks and ground truth to validate the research.

In Computer Graphics (CG), researchers have begun to evaluate what is the best way to convey emotion in animated characters through experiments with subjects, such as (Paleari & Lisetti, 2006; Bevacqua et al., 2007; Orvalho & Sousa, 2009; Niewiadomski et al., 2009; Queiroz, Braun, et al., 2010). Focusing on eye expressiveness, the work of (Queiroz, Barros, & Musse, 2008) investigates the impact of different eye behaviors (for example, to roll the eyeballs around to suggest an ironic behavior independent of the facial expression). Another experimental approach focused on eyes is found in (Normoyle et al., 2013) where eye movements conveyed trust independently of some facial expressions. With another purpose, but related to identifying facial expressions in synthetic faces, is the work of (Fernandes, Alves, Miranda, Queirós, & Orvalho, 2011) that presents a system to help children with autism to learn about facial expressions using CG characters. Some recent work focused in facial motion capture and real-time retargeting (Bhat, Goldenthal, Ye, Mallet, & Koperwas, 2013; H. Li, Yu, Ye, & Bregler, 2013) also discuss the importance of preserving microexpressions, although they do not guarantee it yet: the framerate of and inherent noise in the ordinary imaging devices used in this kind of application present technical challenges to robustly capturing microexpressions.

Focusing on conveying more subtle and complex emotional expressions, Rehm and André (Rehm & André, 2005) implemented some "fake expressions" (modifying subtly the real expression combining it with an opposite emotion) with the objective of portraying a character who was lying to the users. Their experiments showed that that participants were able to notice the differences between genuine and faked smiles. Approaches to evaluating a virtual character's believability are also presented in (Rehm, 2008; Demeure et al., 2011; de Melo et al., 2011), in the context of virtual agents applications. Research focused in the perception of different types of smiles using CG characters are found in (Ochs & Pelachaud, 2012). Focusing on microexpressions, the work of (Zielke et al., 2011) aims to generate facial expressions with subtle differences in the movements, in order to produce different meanings to the audience. However, they do not evaluate users' affective responses to their animations.

The experiments in this work are inspired by three reported psychological studies. The first experiment is in Bornemann *et al.* (Bornemann et al., 2011) where microexpressions are presented fast enough (10ms and 20ms exposure) to ensure that people cannot perceive them consciously. The question asked is whether such unaware subjects can "feel" the emotion of this expression. To test this they showed the participants 10ms (or 20ms) of a happy or angry expression before 2s of neutral faces or dotted patterns. The participants had to respond if they considered the sequence happy, neutral or angry, while their facial reactions to the image sequences were also measured with electromyography (EMG). Based on the accuracy of the survey and the distinct EMG responses, they concluded that people can identify these subliminal expressions. Although that work focused on the internal feedback from subliminal stimuli (since the participants reported they did not see the angry and happy faces), we took this experimental methodology as our starting point in our evaluations. Their results reinforce our hypothesis by showing the importance of including microexpressions in a subtle way that may suggest a second emotion stream.

The second influential paper is by Shen *et al.* (Shen et al., 2012), which tested two experimental methodologies they called the BART (Brief Affect Recognition Test) condition and the METT (Microexpression Training Tool) paradigm, based on Ekman's work (Ekman & Friesen, 1974) and (Ekman, 2002). The BART condition consisted of showing the six universal expressions after a fixation point (BART), and in the METT paradigm the universal expressions are exhibited between two neutral face sequences. For both experiments, the participants had to say which emotion they perceived. In (Shen et al., 2012), they tried different ranges of expression exhibition times (from 40ms to 300ms) using BART and METT and investigated the possible upper limit to microexpression duration. They concluded that above 160ms identification accuracy begins to stabilize, indicating an upper limit to the microexpressions (*i.e.*, differentiating them from the macroexpressions). The lower and upper limits of microexpression duration were also explored in the work of (Yan, Wu, Liang, Chen, & Fu, 2013), which determined, based on their distribution and estimation, that a microexpression could be defined by its total duration less than 500ms or its onset duration less than 260ms. The work of Shen *et al.* was important to our methodology since it provided an empirical basis for microexpression duration and suggested the best method (METT) for presentation to the experiment subjects.

We also decided to exploit, as a preliminary study, the idea of priming effects on the participants. The idea of priming effect, as discussed in (Agafonov, 2010), is that conscious visual perception is a result of a nonconscious decision to consciously perceive. In this context, the work of (W. Li et al., 2008) is the third that contributed to our methodology. In this work, they showed subjects surprise expressions preceded by 30ms of happy or fear expressions and asked if they considered the observed expression "positive" or "negative". Their objective was the investigation of affective priming effects in people with an anxiety trait; while differing from our objective to investigate how the perception of a microexpression can impact the evaluation of an emotional sequence as a whole, their experimental methodology of combining macro- and microexpressions helped us to create our animation videos.

Also in this context of priming effects is the work of Prochnow *et al.* (Prochnow et al., 2013), that combined behavioral and fMRI (functional Magnetic Resonance Imaging) studies, aiming at examining whether or not consciously accessible (subliminal) emotional facial expressions influence empathic judgments and which brain activations are related to it. Their experiment showed that subliminal emotional facial expressions of 40 ms duration affect the judgments of the subsequent neutral facial expressions. Smith (Smith, 2012) investigated the time course of processing of three facial expressions (fearful, disgusted, and happy) plus an emotionally neutral face, during objectively unaware and aware perception. Participants completed the challenging "which expression?" task in response to briefly presented masked expressive faces. Although the participant's behavioral responses did not differentiate between the emotional content of the stimuli in the unaware condition, they observed that the activity over frontal and occipitotemporal brain regions had an emotional modulation of the neuronal response. These results reinforce the importance of our investigation, indicating that even when the stimuli are subliminal, they are processed by the human brain and can impact one's judgments or decisions.

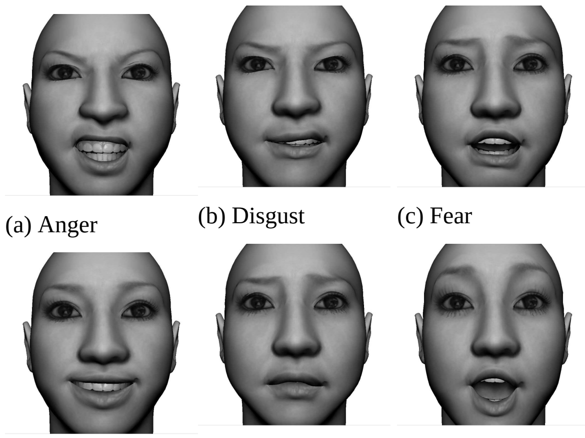
Methodology

Inspired by the psychological studies mentioned above (Bornemann et al., 2011; Shen et al., 2012; W. Li et al., 2008), we performed two sets of experiments with subjects. For each one, we prepared a survey with short video sequences of animated virtual faces performing the universal facial expressions and asked subjects to record their impressions (details about the questions are given below).

Our first experiment was conducted totally via the Internet, while the second experiment was performed later, with supervision over the participants, in order to validate and complement the first experiment. The survey structure of both was quite similar, altough the second experiment had an extra set of questions we judged important to add after considering the results of the first one.

Experiment 1

For the first experiment, we opted to do a web survey, in order to get more participant responses. The only requirement on the participants was to be connected to the Internet with a bandwidth that allowed them to play the videos fluidly. The participants were instructed not to pause or explore the videos' frames until they finished the entire survey, and they were encouraged to write about their impressions in the



(a) Anger (b) Disgust (c) Fear

(d) Happiness (e) Sadness (f) Surprise

Figure 1. The 6 universal emotions represented by our 3D face that were shown to the participants at the beginning of the experiment.

optional "comments" field. Also, inspired by the aforementioned methodologies that used a training stage, our experiments first showed participants pictures of a virtual character performing the six universal expressions. These emotions were crafted using the software FaceGen[1] (more details about the expression modeling are presented in this section), inspired by Ekman's universal expressions. We decided to present these pictures because even if participants recognized emotions, they could not know the concept of the universal emotions, so this training stage is important to instruct the participants about the types of emotions they could observe in the videos. Figure 1 shows the training images presented to the subjects.

The experiment has two parts, in order to investigate different aspects of the participants' perceptions. Each part (we named Part 1 and Part 2) has 10 questions. Each question consists of a short video and a set of exclusionary options that the participant must check according to her perceptions from the video. Also, for each question we asked the participant how many times she watched the video: since it was a web survey we could not assess the participant's ability to respond to a question if videos sometimes failed to run fluidly. These are some aspects we improved in the second set of experiments.

Part1: METT paradigm. The Part 1 stimuli were created inspired by Shen *et al.* (Shen et al., 2012), using the METT paradigm for the presentation of the images: presenting microexpression frames between neutral frames. The main objectives of these questions were to verify if the accuracy and concordance of the participant's responses concerning synthetic faces matched the empirical results done with the photos of real people in (Shen et al., 2012). We chose to present the microexpression with duration 100ms, between two sequences of 2s with a neutral face. The METT paradigm and the duration of 100ms were chosen based on Shen's work, which tested various durations and verified that above 160ms microexpression identification accuracy begins to stabilize and indicates a possible upper limit to its duration. Also, in their experiments these durations in the METT paradigm achieve better accuracy compared to the BART condition.

The questions of Part 1 are preceded by the message: *"Pay attention on the following animations. In all of them a very brief emotion is performed. Emotions can repeat more than once. Let's see what you perceive."*. Figure 2 shows the structure of each question from this set of questions. For each question, a video is presented following the scheme as shown in Figure 3, varying the *inbetween* emotion; the response options given to the participant were the six universal emotion names, "None" or "I don't know". These last two options were not present in (Shen et al., 2012), but we opted to include them in order to minimize random responses.

Which emotion did the briefly presented face display?
( )Anger
( ) Happiness
( ) Sadness
( ) Fear
( ) Disgust
( ) Surprise
( ) No way, I just see a neutral face!
( ) I don't know (I perceived something but I don't know what)

How many times (approximately) did you have to see this video to perceive something? [ ]

Figure 2. Structure of the questions of Part 1 of the survey (present in experiment sets 1 and 2).

In this set of experiments, we have two questions with the emotions happiness, sadness, anger and disgust, and one question with fear and surprise, having a total of 12 questions.

Part 2: Identifying Macro- and Microexpressions. Part 2 of the experiment investigates the participant's perception of macro- and microexpressions in some short character animations. Our hypothesis is that the participants can perceive a second emotion when we add a quick expression into a regular facial expression timeline. We also investigate if

[1] Singular Inversions Inc. – `http://www.facegen.com/`

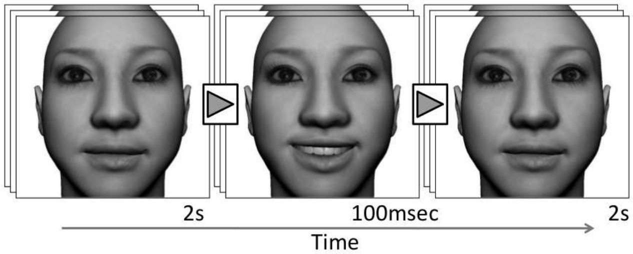


Figure 3. Overview of the questions inspired by the METT paradigm.

they can correctly identify this second emotion. We created 10 videos in which a 3D face performs one of the six universal emotions as the main expression (the macroexpression) preceded by another very brief universal emotion (microexpression). This animation scheme was inspired by the experiment of Li *et al.* (W. Li et al., 2008), in which surprise expressions were preceded by a brief happy or fear expression and subjects were asked if they considered it "positive" or "negative". Our approach differs somewhat, since our objectives are different. First, we opted to explore some different combinations of expressions presented as macro- and microexpressions, in order to investigate our hypothesis. We also chose to create animated expressions (not just static emotion frames), since we are interested in evaluating a simple way to convey subtle microexpressions on a 3D animated character. Finally, we opted to ask the participant which emotion she perceived as the main expression and, if she perceived a secondary emotion, which one she thought it was. Our objective in this part is to verify:

- if participants recognize (correctly) the main (macro) emotion
- if participants perceive a secondary emotion (microexpression)
- if participants recognize (correctly) the secondary emotion

The questions of this part are preceded by the message: *"Pay attention on the following animations. The character is expressing one emotion, but maybe she is hiding something else.. Let's see what you think."*. Each question has two subquestions, asking the participant to identify the *A*) main emotion and *B*) the secondary emotion. Figure 4 shows the structure of each question from this set of questions. Then, for each question, a video is presented following the scheme as shown in Figure 5, varying the main and secondary emotions. The options to the participant were the six universal emotion names for the subquestion *A*) and for subquestion *B*) we included the options "None" or "I don't know" in addition to the emotions.

The combinations of the primary and secondary emotions were chosen randomly. Because of the number of questions, we did not generate all the possible combinations. Table 1

A) Which main emotion did the presented face display?
( ) Anger
( ) Happiness
( ) Surprise
( ) Sadness
( ) Disgust
( ) Fear

B) Do you think she is feeling something else? Which emotion?
( )Anger
( ) Happiness
( ) Surprise
( ) Sadness
( ) Disgust
( ) Fear
( ) None (I didn't perceive anything else)
( )I don't know (I perceived something but I don't know what)

How many times (approximately) did you have to see this video to perceive something? [ ]

Figure 4. Structure of the questions of Part 2 of the survey (present in experiment sets 1 and 2).

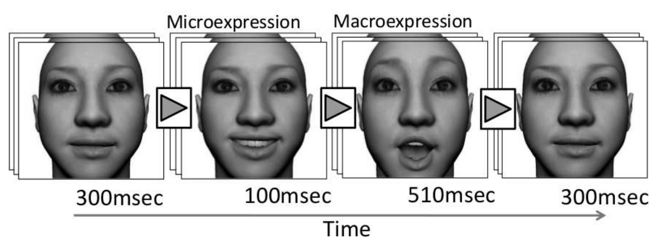


Figure 5. Overview of the questions with main and secondary emotions.

shows the combinations considered in this experiment.

Experiment 2

The second set of experiments was created in order to complement the results of the first one: mainly to verify if the lack of control over the participants (no supervision) and the video frame rate (because they were provided by streaming) on the first experiment did or did not impact the results. This time, the participants were physically present in the lab and were supervised during the experiment, and the videos were not hosted on the Internet (i.e., they are stored on a local machine).

This new set of experiments has 3 parts: Part 1 and 2 are as described in Experiment 1 and a new Part 3 (to be de-

Table 1
Specification of the trials in Part 2 of Experiment 1

Trial	Macroexpression	Microexpression
1	Happiness	Sadness
2	Surprise	Sadness
3	Sadness	Happiness
4	Fear	Anger
5	Anger	Happiness
6	Fear	Disgust
7	Sadness	Anger
8	Surprise	Fear
9	Surprise	Happiness
10	Happiness	Anger

scribed below). We also decided to add more trials (questions) to the survey, since in the first experiment we did not explore all the emotions in Part 2. This decision, plus the supervision requirement, reduced considerably the number of participants. For Part 1, we created 12 questions (2 per emotion) and for Part 2, 20 questions: the combinations of emotions are presented in Table 2.

Based on the analysis of the results from the first experiment set (which we will fully discuss in the next section) that showed low microexpression identification accuracy by the participants, we decided to exploit some participant "subjective impressions" with a new set of questions, we named Part 3.

Part 3: Priming effects. Part 3 of the experiment investigates the participant's perception of realism, deceit, and valence of the character's emotions in the presented videos. In this part, instead of asking participants to identify the emotions, they have to rate the animations on a 1–5 scale according to their impressions, considering:

- the realism of the expression (rating the character's performance from "robotic" to "realistic")
- the deceit of the expression, i.e., if the participant felt the character seems to be pretending an emotion or not (rating the character's performance from "fake" to "true")
- the valence of the expression, i.e., if participant considered the emotion as being negative or positive (rating the character's emotion from "negative" to "positive")

This animation scheme was also inspired by the experiment of Li *et al.* (W. Li et al., 2008), in which surprise expressions were preceded by a brief happy or fear expression and subjects were asked if they considered it "positive" or "negative". For this experiment part, we chose 6 combinations of primary and secondary emotions, considering 3 primary emotions preceeded by a positive and a negative secondary emotion. For a positive emotion we selected "happiness", and for negative emotions we used "sadness" and "fear".

The questions of this part are preceded by the message: *"Pay attention on the following animations. The character is expressing one emotion, but maybe she is hiding something else.. Let's see what you think."*. Each question has three subquestions (presented in separate trials), asking the participant to rate the: *A*) realism; *B*) deceit and *C*) valence of the expression. Figure 6 shows the structure of each question from this set of questions. Then, for each question, a video was presented following the scheme as shown in Figure 5 (the same as for Part 2), varying the main and secondary emotions.

Table 3
Specification of the trials of Part 3 of Experiment 2

Trial	Macroexpression	Microexpression
1	Happiness	Sadness
2	Happiness	Happiness
3	Surprise	Fear
4	Surprise	Happiness
5	Sadness	Happiness
6	Sadness	Fear

Figure 6. Structure of the questions of Part 3 of the survey (just on experiment 2).

The combinations used in the survey are presented in Table 3.

Facial Animation

It is important to emphasize that a macro- (main expression) and a microexpression conceptually differ from one to another only by their duration (Shen et al., 2012). So we used the same key expressions of the universal emotions to create the animations of macro- and microexpressions. Our

Table 2
Specification of the trials in Part 2 of Experiment 2

Trial	Macroexpression	Microexpresion	Trial	Macroexpression	Microexpression
1	Happiness	Sadness	11	Disgust	Sadness
2	Surprise	Sadness	12	Anger	Surprise
3	Sadness	Happiness	13	Fear	Surprise
4	Fear	Anger	14	Disgust	Surprise
5	Anger	Happiness	15	Happiness	Surprise
6	Fear	Disgust	16	Sadness	Disgust
7	Sadness	Anger	17	Fear	Disgust
8	Surprise	Fear	18	Disgust	Fear
9	Surprise	Happiness	19	Surprise	Disgust
10	Happiness	Anger	20	Fear	Happiness

model of facial animation is based on blendshape interpolation and the animations were created using the facial animation control tool from (Queiroz, Cohen, & Musse, 2010), using 3D faces generated with the FaceGen software.

The facial expressions were modeled using the key expressions that FaceGen provides, inspired by Ekman's universal expressions. We used two different virtual faces, also created in FaceGen. To create the animation frames, we edited scripts describing the expressions (keyframes) and their total time in the animation. The transition between two expression is done using linear interpolation, according to the specified expression durations.

Results and Discussion

For Experiment 1, we collected the responses of 84 participants over a five day period. All the participants were academics, 72 male and 12 female, with mean age 27.57, with standard deviation 9.15. For experiment 2, we collected the responses over a 3 day period with 10 participants, also academics, 7 male and 3 female, with mean age 26.4 and standard deviation 7.06. Two of the volunteers participated of both sets of experiments.

The mean percentage of correct responses of all participants is shown in Table 4. This table also shows the mean percentage of correct responses in Part 1 and Part 2 of the survey (as explained in previous section), as well the mean percentage of correct responses to the two sets of questions of Part 2, corresponding to the identification of the main (A), secondary (B) and both expressions.

In order to investigate the degree to which the participants recognized or confused the expressions, we computed confusion matrices for each part of the survey in both experiments. Table 5 shows the confusion matrix for the responses to Part 1 of the survey. The diagonal of the matrix shows the accuracy percentage for each emotion present in the questions of this part. We also calculated the kappa value, in order to measure the concordance between the participants (Landis & Koch, 1977). For Part 1, the kappa value is 0.74 in Experiment 1 and 0.51 in Experiment 2, which means substantial and moderate agreement, respectively. We also calculate the concordance of the confusion matrix presented in (Shen et al., 2012), and the kappa value obtained from that data is 0.64; this can be considered substantial agreement between the two studies. It is important to emphasize that the confusion matrix presented in that paper has the mean accuracy of all the tests they performed (with BART and METT tests and different durations of microexpressions). Comparing both experiments, we observed high accuracy and agreement on the first one. Looking at the confusion matrices, we can observe that participants on the second experiment responded they did not know the expression more often than in the first experiment.

Considering the mean percentage of the accuracy per emotion in Table 5 for Experiment 1, $\bar{x}_1 = 78.17\%$ and standard deviation 17.88%, we compared reasonably well with the mean percentage of the accuracy of (Shen et al., 2012) in the METT experiment with duration of 120ms, $\bar{x}_2 = 69.77\%$ and standard deviation 10.07%, with significance of 0.05. The two-tailed t-test considering different variances generates a p-value=0.76, which indicates no significant difference between $\bar{x}_1$ and $\bar{x}_2$. For Experiment 2, we obtained the mean percentage $\bar{x}_3 = 58.33\%$ and standard deviation 19.64%. Comparing these to Shen's, we obtain the p-value=0.26, and comparing to Experiment 1, we obtained p-value= 0.25, which also means no significant difference. Based on this, we can say that the use of our virtual faces performing microexpressions (chosen from Ekman's universal emotion set) generated results compatible with the experiments using photographs of real people.

As we described in the previous section, we chose to perform Experiment 1 with a large number of participants in order to collect varied responses. This decision also influenced the number of questions in the survey. We decided to limit the survey to 20 questions (actually, 30 tries, because Part 2 questions have subquestions *A*) and *B*), asking for the macro- and microexpressions perceived) in order to avoid participant

Table 4
Mean and standard deviation of the correct responses of all participants.

Experiment 1	Part 1	Part 2			Total
		A)	B)	A) and B)	
mean	80.00%	73.33%	45.00%	41.19%	58.57%
std. dev.	15.75%	27.65%	31.03%	30.20%	19.47%
Experiment 2	**Part 1**	**Part 2**			**Total**
		A)	B)	A) and B)	
mean	58.33%	65.50%	48.50%	43.50%	57.31%
std. dev.	19.92%	16.38%	16.63%	16.31%	18.59%

Table 5
Confusion matrix with the accuracy percentage of participants' recognition of the six emotions as microexpressions following the METT paradigm in Part 1 of the survey.

Experiment 1	Anger	Happiness	Sadness	Fear	Disgust	Surprise	no emotion	don't know
Anger	**92.26%**	0.60%	0.00%	2.98%	3.57%	0.00%	0.00%	0.60%
Happiness	0.60%	**87.50%**	0.60%	0.60%	0.60%	2.98%	1.19%	5.95%
Sadness	0.00%	0.60%	**75.60%**	10.12%	6.55%	0.60%	1.79%	4.76%
Fear	3.57%	0.00%	2.38%	**45.24%**	4.76%	30.95%	1.19%	11.90%
Disgust	19.05%	0.00%	1.79%	0.00%	**75.60%**	0.60%	0.60%	2.38%
Surprise	0.00%	1.19%	0.00%	2.38%	1.19%	**92.86%**	1.19%	1.19%
Experiment 2	Anger	Happiness	Sadness	Fear	Disgust	Surprise	no emotion	don't know
Anger	**80%**	5%	0%	0%	0%	5%	0%	10%
Happiness	10%	**70%**	0%	0%	5%	0%	0%	15%
Sadness	0%	5%	**55%**	20%	5%	5%	0%	10%
Fear	0%	0%	10%	**25%**	20%	20%	5%	20%
Disgust	40%	0%	5%	0%	**50%**	0%	0%	5%
Surprise	0%	0%	0%	10%	0%	**70%**	5%	15%

exhaustion. The drawback is that, with this limited number of questions, we could not explore all the possible combinations of emotions playing the role of macro- and microexpressions in Part 2. On the other hand, for Experiment 2, we increased the number of questions (12 for Part 1 and 20 for Part 2 – a total of 52 trials). This fact, plus the decision of supervising the participants while performing the experiments, decreased the number of participants: we had a considerable number of people refuse to do the experiment when they were told the number of trials. The advantage, in this case, was that we could exploit each emotion as a micro- and macroexpression at least once (see Tables 1 and 2). This situation pointed out to us that, for future work, we will need to exploit ways to motivate the participants to perform longer tests. For this reason, we consider the Experiment 2 a preliminary study, which helped to confirm the results from the first experiment and pointed to the need for some improvements in our experimental methodology.

The confusion matrices for the questions of Part 2, considering the percentage of the accuracy of recognition of the macro- and microexpressions, are presented in Tables 6 and 7. The kappa value for the confusion matrix for Part 2 A) (macroexpession) is 0.6 for both Experiment 1 and 2, which is considered substantial agreement. However, for Part 2 B), the kappa value for Experiment 1 is 0.32 and 0.59 for Experiment 2, which is considered fair and moderate agreement, respectively. In fact, we can notice looking at Table 7 that most participants either confused the secondary emotion, or did not perceive it in the animations.

Observing the confusion matrices of Part 1 and Part 2 A), we can see that, although the facial expression with the primary emotion of Part 2 has a duration longer than the expression of Part 1 (510msec *vs* 100msec), the accuracy of recognition per emotion and concordance rate was lower in Part 2 for Experiment 1 and higher for Experiment 2. Consider the mean 67.62% of the percentage of accuracy for the 5 emotions presented in Part 2 A) of Experiment 1 (standard deviation 24.18%) and 78.17% the mean of these same emotions in Part 1 (standard deviation 17.88%). The p-value=0.44 of the two-tailed t-test considering different variance indicates there is no significant difference between them, with significance of 0.05. For Experiment 2, if we compare the mean 58.33% (standard deviation 19.66%) from Part 1 and 66.67% (standard deviation 16.16%) obtained from Part 2 A), we also obtain the p-value=0.44, which means there is no significant difference between them. Based on these results, we can

Table 6

Confusion matrix with the accuracy percentage of participants' recognition of the six emotions as macroexpressions in Part 2 of the survey. Note that we do not create a question with the main emotion disgust in this section of the survey.

Experiment 1	Anger	Happiness	Surprise	Sadness	Disgust	Fear
Anger	**70.24%**	13.10%	7.74%	1.79%	3.57%	3.57%
Happiness	8.93%	**86.31%**	1.19%	1.79%	1.79%	0.00%
Surprise	0.40%	7.94%	**83.33%**	3.57%	1.59%	3.17%
Sadness	12.50%	6.55%	1.79%	**72.02%**	2.38%	4.76%
Disgust	-	-	-	-	-	-
Fear	28.57%	0.00%	22.62%	2.38%	20.24%	**26.19%**
Experiment 2	Anger	Happiness	Surprise	Sadness	Disgust	Fear
Anger	**70%**	3.33%	13.33%	3.33%	6.67%	3.33%
Happiness	3.33%	**90%**	6.67%	0%	0%	0%
Surprise	10%	10%	**65%**	7.5%	5%	2.5%
Sadness	13.33%	3.33%	0%	**76.67%**	3.33%	3.33%
Disgust	23.33%	3.33%	13.33%	6.67%	**53.33%**	0%
Fear	17.5%	5%	25%	7.5%	0%	**45%**

Table 7

Confusion matrix with the accuracy percentage of participants' recognition of the six emotions as microexpressions in Part 2 of the survey. In this section, we do not include questions with the emotions disgust and surprise.

Experiment 1	Anger	Happiness	Surprise	Sadness	Disgust	Fear	no emotion	don't know
Anger	**48.41%**	8.33%	5.16%	9.92%	12.70%	6.35%	4.76%	4.37%
Happiness	10.71%	**56.75%**	9.13%	6.75%	3.57%	0.79%	8.73%	3.57%
Surprise	-	-	-	-	-	-	-	-
Sadness	0.00%	8.33%	11.90%	**47.02%**	2.38%	4.76%	19.64%	5.95%
Disgust	-	-	-	-	-	-	-	-
Fear	13.69%	2.98%	25.00%	8.33%	9.52%	**20.24%**	11.31%	8.93%
Experiment 2	Anger	Happiness	Surprise	Sadness	Disgust	Fear	no emotion	don't know
Anger	**80.96%**	4.76%	4.76%	4.76%	4.76%	0%	0%	0%
Happiness	0%	**82.14%**	3.57%	3.57%	0%	7.14%	0%	3.57%
Surprise	0%	0%	**67.86%**	10.71%	3.57%	10.71%	3.57%	3.57%
Sadness	4.76%	4.76%	4.76%	**47.62%**	9.52%	9.52%	19.05%	0%
Disgust	14.29%	4.76%	0%	0%	**71.43%**	0%	9.52%	0%
Fear	0%	4.76%	28.57%	9.52%	0%	**42.86%**	0%	14.29%

say that the microexpression does not impact significantly the recognition of the macroexpression.

Considering Experiment 2 (which has a better distribution of the samples of emotions as macro- and microexpressions), with mean 65.48% of the percentage of accuracy in Part 2 B) (standard deviation 16.67%) and the mean from Part 1 (66.67% with standard deviation 16.16%) we obtain a p-value=0.51, which indicates that, with 5% significance, there is no significant difference between them. The correlation between these sets of accuracies per emotion is 0.8, which indicates a strong correlation. It can suggest (but not prove) that the presence of another expression does not impact the recognition of the microexpression compared to the recognition rate with no other expression (as in Part 1).

In Experiment 1, most of participants responded they watched the videos once. It is important to emphasize that in the instructions we did not forbid the participants to watch the videos more than once (mainly because we know that sometimes online streaming can fail), we just asked them to never stop or explore the frames. The mean of the responses of how many times users watched the videos was 1.27 times and standard deviation 0.71. Outliers were not considered.

We also observed the importance of the options "None" and "I don't know" in the responses, in the sense that this showed that many times the participant could perceive some emotion, but could not identify it. We can also notice that, in both experiments, the emotion "sadness", when played as a microexpression, was not perceived by 19% of the participants, differing considerably from the other emotions. This particular case could be studied in future work. To conclude, Figure 7 summarizes the accuracies per emotion of all the experiments, including the mean accuracies of the work

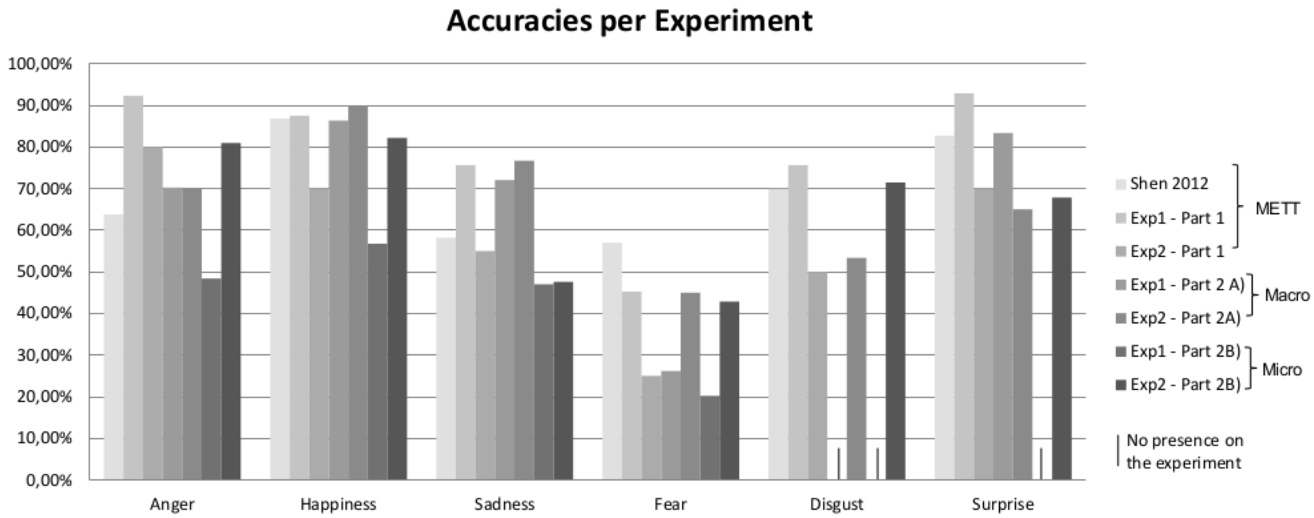


Figure 7. Accuracies per emotion of all the experiments.

of (Shen et al., 2012).

We can say that, in all the stimuli, most people perceived the existence of a second emotion. The accuracy rates, however, suggest that it is necessary to perform more studies about how to convey it in a more realistic way in computer animations to enhance their semantics. Microexpressions are subtle and not all people perceive them naturally. They may need more training to perceive and recognize their meaning (Ekman & Friesen, 1969; Ekman, 2002, 2009). However, it is important that in computer graphics their inclusion as a character's second emotion stream could improve believability without necessarily confusing the audience. For example, over the course of an interaction with a virtual character, its secondary emotion may be expressed several times: such repetition may lead to better microexpression perception and recognition rates in the human participant. Our experiments can be considered an initial step to future microexpression animation models that could even cooperate with motion capture models, providing clues to the corrective steps researchers are currently investigating, such as in (Bhat et al., 2013).

We observed that participants had fair and moderate agreement in recognizing the identity (from the universal emotions) when we combined a quick emotion preceding another with a longer duration. We did not propose a specific or novel animation model to combine these emotions, since at this time our focus was to test the participant's perception using the traditional method of blendshape interpolation. We did not take into account the specific duration of each main emotion in any real life situation. In order to conduct a more detailed simulation of macro- and microexpressions, we suggest trying to use microexpression databases (Yan, Wu, Liu, et al., 2013; X. Li et al., 2013). Our results also suggest that future microexpression animation models must take in consideration the different emotions that play the roles of macro- and microexpressions.

Our experiments do not include an emotional context behind each character's performance (i.e., in which context the character performs those facial expressions). We can point to future work in the investigation of the impact of microexpressions considering this context, expecting that this additional feedback should give to the participant clues about the true emotion the character is feeling, or at least to some internal emotional mood or state, or to potential emotional conflicts. Other important future work is to investigate more deeply the combinations of macro- and microexpressions, since our limited number of questions did not explore all combinations.

Considering Part 3 of Experiment 2, we can notice that, in general, the participants had varied responses (we do not see a clear tendency in the ratings). Table 8 shows the participants' ratings per trial. The participants considered more "realistic" the animations with emotion "happiness" (preceeded by "happiness" and "sad" microexpressions). Animations with "sadness" and "surprise" (preceded by "happiness" and "fear") showed the most divergent opinions about realism. Perhaps the lack of situational context led to such realism ambiguities.

Considering the participant's impressions about the deceit of the expression, we see that "happiness" before the other emotions had more evaluations as a "fake" expression. It could be a clue that emotions with opposite valences generate the impression of contradictory emotions (as expected), but this subject should be investigated more extensively. On the other hand, 60% of the participants considered more "true" the emotion where "sadness" was preceded by "fear". In this case, the two emotions (considered negative in valence), seem to reinforce the credibility of the expression. Table 9 shows the participants' ratings per trial.

Table 8
Percentage of Ratings for Realism

Ratings	Sad/Happy	Happy/Happy	Happy/Surprise	Fear/Surprise	Happy/Sad	Fear/Sad	Average	Std. dev.
1	20%	20%	30%	20%	20%	20%	22%	4.08%
2	20%	0%	20%	10%	20%	10%	13%	8.16%
3	20%	0%	20%	40%	20%	30%	22%	13.29%
4	40%	60%	30%	30%	20%	30%	35%	13.78%
5	0%	20%	0%	0%	20%	10%	8%	9.83%

Table 9
Percentage of Ratings for Deceit

Ratings	Sad/Happy	Happy/Happy	Happy/Surprise	Fear/Surprise	Happy/Sad	Fear/Sad	Average	Std. dev.
1	30%	20%	30%	20%	30%	0%	21.67%	11.69%
2	10%	10%	10%	10%	10%	0%	8.33%	4.08%
3	40%	10%	20%	50%	20%	30%	28.33%	14.72%
4	20%	10%	20%	10%	10%	60%	21.67%	19.41%
5	0%	50%	20%	10%	30%	10%	20.00%	17.89%

Finally, considering the participants' impressions about the valence of the whole expression, we can notice differences. In the animations of "surprise" (which can be considered the most neutral expression in valence (W. Li et al., 2008)), when preceded by "happiness", most of participants evaluated it as a "positive" emotion, while when preceded by "fear", most of participants evaluated it as "negative". It did not occur with the animations with "sadness" (an emotion with negative valence) preceded by the same microexpressions, where in both cases most of participants rated the whole expression as more negative. Considering the animations with "happiness", the presence of the negative microexpression "sadness" caused some evaluations of the emotion as negative. Table 10 shows the participants' ratings per trial.

Final Remarks

This paper presents two studies on the human perception of microexpressions performed by animated character faces. The main contributions of this work are the evaluation methodology from the point of view of computer animation, and the apparent perceptual influence that microexpressions can have on the perceived emotional state of such characters. We hope to improve facial animations and visually enhance the emotional behavior and depth of the characters.

Concerning the experiments we performed with subjects, we can observe that most of the participants recognized the foreground (macro) emotion and most of the time they perceived the presence of the second (micro) emotion in the animations, although they did not identify it correctly in some samples. It is also important to emphasize that, because of the small N in experiment 2, results should be considered as offering preliminary support, and that further work is needed in order to draw a more definitive conclusion, mainly with respect to the priming effects it caused to the participants (Part 3 of the experiment set).

Results show that the recognition of microexpressions following the METT paradigm with virtual characters had substantial agreement with the results obtained in (Shen et al., 2012) who just used photographs of real people. Also, for our animated sequences, most of participants perceived the existence of a second emotion, which suggests we can accept our hypothesis. Although there are accuracies in the recognition of the microexpression, this just points to a need for more studies on how to convey microexpressions more effectively, perhaps through a mechanism as simple as periodic repetition to enhance perceptual processing.

Also, our study considering subject impressions of realism, deceit and valence suggests that the combination of emotions with opposite valences changes the perception of the expression as whole. This subject should be studied more deeply, starting from observed clues on the increase of realism and deceit by combining emotions with the same valence, as well as decreasing deceit and changing valence perception when combining emotions with opposite valence. Our experiments are a preliminary study: considering the small number of emotion combinations, others still remain for investigation. Moving beyond the universal emotions constitutes a further direction for research.

In the context of storytelling, the external emotional state of a character is visually reflected on its face. Our studies demonstrate that, by using microexpressions, additional emotional content derived from the character's internal mood or state may be subtly depicted in a game or VR setting. Such a non-player character would exhibit additional emotional depth and complexity when it interacts with the player, enhancing its social complexity and believability. For example, microexpressions may be used to generate possible feelings of suspicion (when there are perceptible subliminal

Table 10
Percentage of Ratings for Valence

Ratings	Sad/Happy	Happy/Happy	Happy/Surprise	Fear/Surprise	Happy/Sad	Fear/Sad
1	10%	0%	10%	20%	40%	40%
2	20%	0%	10%	30%	40%	40%
3	10%	10%	20%	30%	20%	10%
4	30%	50%	30%	10%	0%	10%
5	30%	40%	30%	10%	0%	0%

secondary emotions) or trust (when there are not). We would be able to add to the player's experience the challenge of recognizing the emotional subtlety present in real life in order to evolve the game or understand character interrelationships in a virtual world. This approach might also be exploited in simulation tools to help people with social interactions, a situation that arises in the understanding and treatment of autism, for example.

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