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ORIGINAL ARTICLE

Emotional responses to watching and touching 3d emotional face in a virtual environment

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Abstract

Facial expressions play a crucial role in modulating the emotional responses in the viewers. Touch is an important factor in shaping human emotions and social communication. The objective of this study is to investigate the effects of viewing and touching a virtual emotional face on the emotional responses of a viewer/toucher. In the case of touching the model, the effects of physical properties, namely stiffness and texture, are examined. Emotional facial expressions for neutrality, anger, fear, disgust, happiness, surprise, and sadness are developed and experimentally validated for the visual stimuli whereas four combinations of stiffness/texture properties are examined for the physical properties (low/high stiffness and smooth/rough texture). 25 participants viewed and touched the virtual emotional face and reported their respective emotional responses. The results showed that watching angry, happy, surprised, and sad faces significantly increased their anger, happiness, surprise, and sadness levels, respectively ($p < 0.05$). Watching a scared or a sad face significantly modulated the participants' surprise levels ($p < 0.05$). On the other hand, viewing and touching an angry face significantly reduced the surprise level in the toucher ($p < 0.05$). As for differences based on physical properties, our results suggested that viewing and touching the disgusted face significantly modulated sadness. In particular, high stiffness/rough texture condition resulted in a significant increase in sadness while viewing and touching the disgusted face, compared to the high stiffness/smooth texture condition ($p < 0.01$). These conclusions suggest that viewing and touching an emotional face in a virtual environment modulates the emotional responses in the viewer/toucher. Findings of this study help the field of virtual reality to expand to a greater understanding of building emotionally compelling interpersonal interactions in the virtual environments.

Keywords Emotions · Facial expressions · Haptic interaction · Virtual environments

1 Introduction

Visual stimuli are known to affect the emotional state among individuals (Min et al. 2005; Lane et al. 1999). Among other visual stimuli, Virtual Reality (VR) is an effective tool for creating immersive experiences that are able to originate or influence users' emotional states (Riva et al. 2007). For example, the study in Riva et al. (2007) demonstrated that VR simulation is capable of influencing anxiety and relaxation among viewers, and also highlighted the influence on the emotional state by the sense of presence in virtual world. Similarly, VR has shown its effectiveness to help overcome social phobia and other mental disorders (Klinger et al. 2005).

As for affective communication, the face is a primary channel through which emotions are expressed and facial expressions are of major importance in influencing others' emotions. Several studies have confirmed that facial expressions in virtual environments can induce emotional responses in an observer (Kret et al. 2013). Haptic modality is another affective input medium among other multimodal interactions that influence our emotions. Haptic interactions are known to induce pleasant or unpleasant sensations in humans (Löken et al. 2009; Essick et al. 2010). There have been several research activities studying the role of Haptics (direct or mediated) to elicit or influence emotional responses (Eid and Osman 2016).

Physical properties of the haptic interaction can influence specific emotional responses. We experience tactile stickiness of fabric/clothing against our skin every day that affect

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our perceived comfort level (Cardello et al. 2003). A sensory tactile experience is necessary to experience feelings about the nature of object being touched. A study conducted by Holliins et al. (1993) examined the subjective dimensionality of tactile surface texture perception in multidimensional scaling space. The results showed that *roughness–smoothness* and *hardness–softness* were found to be robust and orthogonal dimensions of tactile perception. Another study evaluated the touch perception of surface texture and their relationship with surfaces' physical properties of confectionery packaging material (Chen et al. 2009). It is found that touch perception is often associated with more than one physical property.

The aim of this study is to investigate the influence of viewing and touching a virtual face displaying emotional facial expressions on emotional responses of viewer/toucher in a virtual environment. To do that, facial expressions of a neutral emotion as well as the six basic emotions (happiness, sadness, anger, disgust, fear, and surprise) are developed and experimentally validated to be perceived as intended. As for the haptic properties, four combinations of stiffness/texture properties (low/high stiffness and smooth/rough texture) are considered for the effects of haptic properties on emotional responses. Haptic properties are rendered using the Geomagic Touch haptic interface with a custom finger grip that was designed specifically for this study. The emotional responses are measured with self-reporting using a slider format (Marcus et al. 2015) and cross-validated with an evaluation of the valence/arousal model. This research largely influences the design of VR-based interpersonal communication systems, involving affective and haptic communication.

2 Related work

2.1 Emotional responses to facial expressions

Emotional expressions of a person lead another person to experience a congruent emotional state (a process referred to as emotional contagion) (Peters and Kashima 2015). It is known that emotional expressions of other may be automatically mimicked (Hess and Fischer 2013) or appraised (Mumenthaler and Sander 2015), this leading directly to convergence in subjective feelings (Hatfield et al. 1993). Anxiety and excitement of another person could affect reported emotions of participants via their risk and importance appraisals (Parkinson and Simons 2009). Furthermore, a highly fearful friend could imply a risky situation and induce similar panic (Lawrence-Wood 2011). These studies focus on the general, visual emotional expressions and not specifically on facial expressions.

The visual cues from the face have been extensively studied for displaying specific emotions (Ko 2018). The foundations of six universal emotional expressions in the facial musculature are well documented (Ekman et al. 1987). While the recognition of emotional facial expressions has received enormous attention in the affective computing literature (Abdi 2010; Aviezer et al. 2008), a few studies examined the effects of emotional facial expressions on eliciting emotional responses in viewers in both real and virtual environments. A comparative study between virtual and real facial expressions is conducted in Dyck et al. (2008). The results showed that sad facial expressions are better recognized (and thus more familiar) when expressed by virtual faces than human faces. In a virtual environment, a study reported that when participants viewed an emotional face displaying fear, a significant increase in the participants' surprise were observed (Vrticka et al. 2014). These studies did not consider haptic interaction. Therefore, in the current study, we intend to examine the effects of watching and touching emotional facial expressions on perceived and emotional responses of a viewer in a virtual environment.

The signaling of emotions by modalities such as touch has received less attention than other sensory modalities. The cues that arise from facial expressions are also available to the sense of touch, and thus facial emotional expressions can be recognized through touch. Lederman et al. showed that the six universal emotions could be recognize at levels well-above chance when people touched the emotional face of a real actor (up to 74% accuracy) (Lederman et al. 2007). A subsequent study derived similar results for classifying universal facial expressions using simple 2D raised-line displays (Lederman et al. 2008). The results suggested that emotions can be interpreted from 2D displays presented haptically as well as visually. Similar results are also obtained with virtual avatars in a virtual environment (Bernal and Maes 2017). Previous studies did not consider the effects of touching an emotional face on the viewer.

2.2 Emotional responses to haptic stimuli

Haptic stimuli are known to affect the emotional state of individuals. To understand the visual and sensory properties of textures and their appeal to human touch, Nagano et al. investigated the relationship between the degrees of haptic invitations of textures and visual textural factors (Nagano et al. 2013). The study reported that the surface glossiness and shape patterns of textures affected the degrees of haptic invitations while surface colors had little impact. Okamoto et al. evaluated the tactile dimensionality of physical properties of materials and concluded that tactile textures have three prominent pairs in psychophysical dimensions namely *(hardness, softness), (roughness, smoothness)*, and *(coldness, warmness)* (Okamoto et al. 2012). In this study, we have selected the first two pairs of psychophysical dimensions to investigate affective responses under different physical properties of tactile textures. To investigate the role of affective touch in human–robot social interaction, Yohanan and MacLean examined humans communicate emotion through touch to a robotic creature that mimics a small animal sitting on a person's lap and their expected reactions (Yohanan and MacLean 2012). The study has summarized human's intent from a touch dictionary when communicating emotions through touch to robots as *protective, comforting, restful, affectionate*, and *playful*. In another study, Israr and Abnousi presented the idea of vibrotactile grids for social touch interactions in form of a wearable haptic device that delivers smooth pleasant strokes on the forearm under different tactile illusory strokes that varied in frequency, amplitude, and duration (Israr and Abnousi 2018). The results suggested that low-frequency strokes were more pleasant, while high-frequency strokes were perceived as smooth and continuous, but not pleasant.

2.3 Emotional responses to physical properties

A plethora of psychophysical and neuropsychological research investigated how surface/material properties affect touch perception in the real world (Lederman and Klatzky 2007; Klatzky and Lederman 2002). For instance, a study explored the relationships between surface physical properties and emotional exchange (Childs and Henson 2007). Tactile stimuli are demonstrated to be linked to the product's rational cause (Barnes et al. 2007) while another study related affective responses to textures to the contact mechanics of the finger on the surface (Childs and Henson 2007). In another study, eight different pine and oak wood surfaces are evaluated using sensory and emotional touch descriptors, through the lateral motion of active fingertip exploration (Bhatta et al. 2017). The results showed that natural and smooth wood surfaces were perceived more positively than coated surfaces.

Findings in the literature suggest a strong potential for interaction between the visual and haptic modalities for modulating emotional responses in a viewer/toucher. The aim of this study is to examine the effects of viewing and touching an emotional face in a virtual environment on emotional responses in the viewer/toucher. Furthermore, the effects of physical properties of touched emotional face on emotional responses in the toucher will be explored.

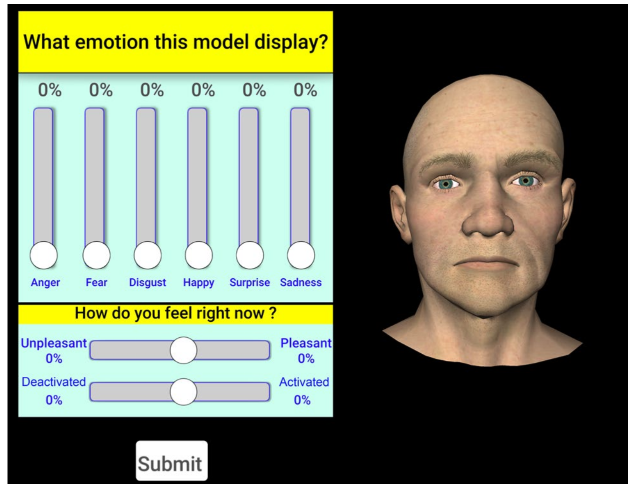

Fig. 1 Graphical User Interface for self-reporting about perceived emotional responses

3 Materials and methods

3.1 Experimental setup

Figure 2a shows the experimental setup with the following components: a custom finger grip attached to the Geomagic Touch haptic device to simulate realistic fingertip touch, a VR headset to simulate immersive visual experience, and the virtual reality simulation. For an enhanced ergonomic haptic experience, a custom finger grip was designed. Figure 2b shows a snapshot of the custom finger grip along with a virtual finger representation in the VR environment. The Geomagic Touch haptic interface is capable of rendering 3-DOF force feedback at 1 kHz. The Oculus Rift device was used to provide an immersive visual experience. The virtual reality simulation displays the 3D model of the virtual face, the fingertip model displaying the position of the toucher's fingertip, and a graphical user interface to display the emotion rating questions and record the participant's responses. The fingertip model was used as a proxy for the real finger inside the virtual environment to provide synchronized visual-haptic feedback at the fingertip.

The simulation software was developed using the Unity3D[1] game engine that provides an easy interface to develop VR applications and their integration with the VR displays. Haptic rendering was implemented using the Unity3D support plugin for the Geomagic Touch device. Haptic properties of the virtual face model were set through the configuration parameters in the haptic application programmable interface. Stiffness parameter was configured programmatically to render whereas texture was simulated using

[1] https://unity.com/.

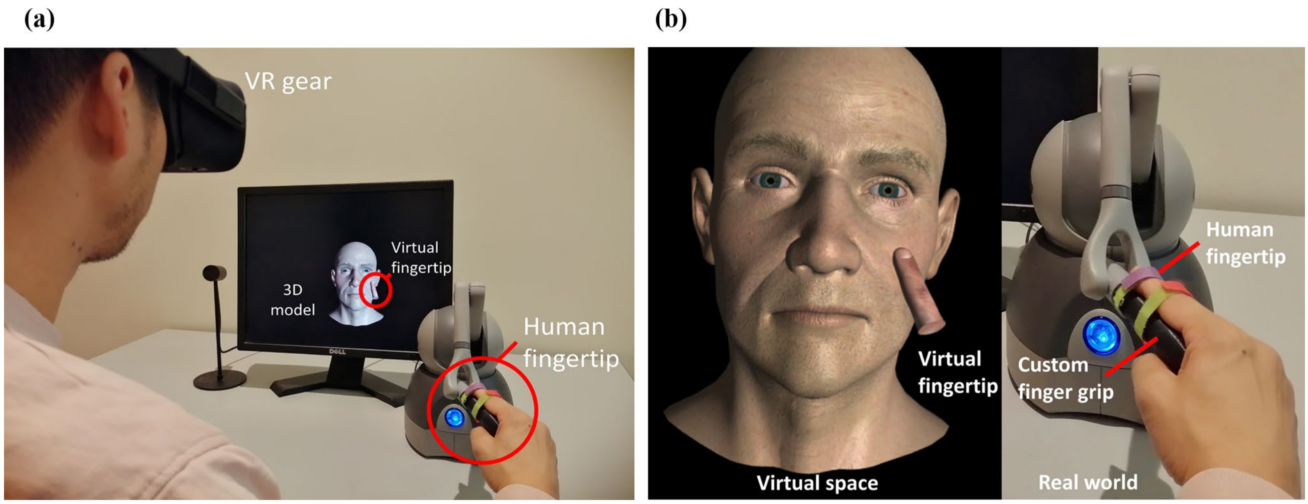

Fig. 2 Experimental setup. **a** A virtual face 3D model for physical touch emulation and head mounted display for an immersive visual experience. **b** A virtual fingertip in virtual reality that matches the user's fingertip. A custom finger grip allows the natural index finger interaction

displacement maps. A single point of interaction was used to emulate the physical contact with the fingertip.

The graphical user interface was designed to record the emotion responses of the participants. The interface had six sliders to rate the level of six basic emotions on scale 0−100 and two sliders for valence and arousal on scale −100 to + 100 (similar to the GUI shown in Fig. 1).

3.2 Visual facial stimuli

Virtual facial stimuli were created using a 3D virtual face model of an adult male to display the neutral and emotional facial expressions[2]. The implementation of the six basic emotional expressions (happiness, sadness, disgust, anger, fear, and surprise), as defined by Paul Ekman (1992), was achieved using the description of facial surface changes as explained within the handbook of Facial Action Coding System (FACS) (Friesen and Ekman 1978). The FACS system describes different action units (AUs) which represent the muscular deformation that produces changes in facial expression in order to display specific emotion. Figure 3 shows the facial expressions for the neutral and the six basic emotions that were used in this study.

The created virtual facial expressions were validated in a pilot study. For this purpose, 15 volunteers (10 females) evaluated the facial expressions according to the expressed emotion in terms of intensity level on a scale of 0–100 points with 0 representing the impression of "not intense at all" and 100 the impression "extremely intense". The participants

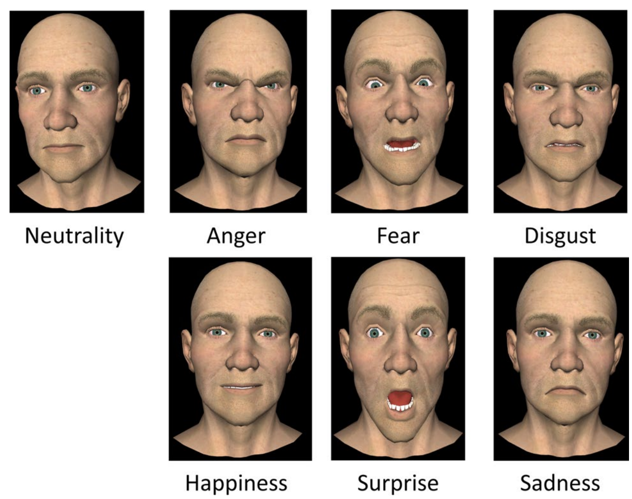

Fig. 3 Stimuli. Neutral 3D face model and six basic emotional 3D face models

were also prompted to provide ratings for valence and arousal in order to cross-validate with the six basic emotional ratings. An application was developed to display the emotional face using the Oculus Rift VR head-mounted display.[3] The application utilized the Leap-motion[4] hand tracker device to enable gesture-based control for the VR graphical user interface. A snapshot of the application as shown in the virtual environment is given in Fig. 1.

The facial expressions were all rated as displaying the intended emotional expression with statistical significance, as shown in Appendix 1. The table shows the average

[2] https://www.turbosquid.com/3d-models/3d-model-male-head-morph-targets/261694.

[3] https://www.oculus.com/rift/.

[4] https://www.leapmotion.com/.

ratings, the standard deviations, and the *p*-values for statistical significance (Wilcoxon signed rank test corrected by Bonferroni Abdi (2010)) for the perceived emotions corresponding to all six emotional facial expressions. The results show that all emotional facial expressions were perceived as intended with statistical significance ($p < 0.01$). Another interesting finding was that surprise facial expressions were confused as fear (in line with previous research findings (Zhao et al. 2013)) whereas anger facial expressions were also confused as disgust. Anger and disgust perception were also cross-validated via the valence rating.

3.3 Haptic facial stimuli

To capture the effects of touch on emotional responses, stiffness and texture properties of the virtual face were changed in each trial of the experiment. Even though the physical properties of the face model were modified, the visual properties remained unchanged for the specific emotion. The stiffness/texture properties of virtual model were modified through the application interface. A force value of 400 N/m was selected to render high-stiffness whereas a force value of 40 N/m was selected for the low-stiffness condition for the Geomagic Touch devices at 1kHz. These are the optimal operating ranges for the Geomagic touch devices. To modify roughness details of the haptic texture, the virtual face model was modified in 3D graphics software (Autodesk 3ds Max[5]).

A vertex displacement map (based on synthetic white noise) was applied to the 3D face model to simulate rough texture. A displacement strength factor of 1 mm was applied to displacement map to generate rough haptic texture whereas the smooth texture was rendered without displacement map. The texture displacement value of 1 mm was selected, so roughness is clearly perceived by the participants' during haptic interaction. Force feedback was rendered by Geomagic Touch haptic interface, with a custom-made finger grip to emulate realistic fingertip touch interaction.

3.4 Participants

A total of 25 subjects of diverse backgrounds (13 females; mean age, 23) took part in the present study. They were recruited through advertisements posted at New York University Abu Dhabi campus. All participants were evaluated for inclusion criteria: an age range of 18 to 55 years, right handed and normal or corrected to normal vision with no history of orthopedic illness. The study was approved by the local Ethics commission and performed according to the Declaration of Helsinki (IRB # 062-2018). All participants gave written informed consent after having received a full description of the study. All data collection and analysis are done under the guidelines of IRB.

3.5 Experimental protocol

The experimental procedure was divided into five sessions conducted in the following order: (1) a training session, (2) watching the neutral face, (3) watching the emotional face, (4) touching the neutral face with varying stiffness/texture properties, and (5) touching the emotional face with varying stiffness/texture properties.

The training sessions provided the participants with an acclimation period for the experimental setup and to become acquainted with the VR headset, the haptic interaction, and the graphical user interface. A training application, developed for this purpose, had a 3D soccer ball with varying stiffness/texture properties (low/high stiffness and smooth/rough texture). Participants were also asked to interact with the training model through the haptic interface to familiarize themselves with the custom finger grip. After completing the training session, participants were asked to rate their emotional responses (0 to 100) including valence and arousal (−100 to +100) on a graphical user interface. The participants were then given a short break (2 min) before moving on to the second session.

The second session involved watching the neutral face and providing emotional responses. The participants were asked to watch the neutral face with no haptic interaction for 7 s and then rate their emotional responses (what they really felt rather than perceived emotion on the virtual face) via the provided graphical user interface. These ratings were used as an individual baseline score for the ratings obtained from watching the emotional face in the third session. The baseline corrections were made in order to reduce the effects of individual differences associated with emotional responses.

In the third session, the participants were instructed to watch the emotional face with no haptic interaction and provide emotional responses, 7 s for each emotional expression. The six universal emotions were presented in random order where participants were prompted to provide emotional responses for each face model separately using the graphical user interface. At the end of the third session, a short break of 2–3 min was given to minimize nausea and fatigue caused by the VR headset.

Session four involved viewing and touching the neutral face with varying stiffness/texture properties and provided ratings for the emotional responses. The participants were instructed to spend 15 s touching the neutral face using the custom fingertip grip in order to feel the stiffness and texture properties of the virtual face and provide ratings for the emotional responses (what the participant really felt during the interaction rather than the perceived emotion of the virtual

[5] https://www.autodesk.com/products/3ds-max/overview.

Table 1 Combinations of physical properties and emotional state of virtual model generated in a counterbalanced order

3(HS/ST)	5(LS/ST)	6(LS/RT)	1(LS/ST)	2(HS/ST)	4(LS/RT)
5(HS/RT)	6(LS/ST)	3(LS/RT)	1(HS/ST)	2(HS/RT)	4(LS/ST)
3(LS/ST)	1(HS/RT)	2(LS/ST)	5(LS/RT)	6(HS/ST)	4(HS/RT)
6(HS/RT)	4(HS/ST)	1(LS/RT)	5(HS/ST)	3(HS/RT)	2(LS/RT)

Numbers from 1–6 indicate anger, fear, disgust, happy, surprise, and sad emotions, respectively. HS/ST, LS/RT, HS/RT, and LS/ST indicate high stiffness/smooth texture, low stiffness/rough texture, high stiffness/rough texture, and low stiffness/smooth texture conditions, respectively

face). The participants experienced four combinations of stiffness/texture properties of the virtual face: low-stiffness and smooth-texture, high-stiffness and smooth-texture, low-stiffness and rough-texture, high-stiffness and rough-texture.

In the fifth session, the participants were asked to perform similar haptic interaction as in session four with 24 different combinations of emotional states of the virtual face and stiffness/texture properties (six emotions multiplied by four combinations of high/low stiffness and smooth/rough texture). Table 1 highlights the different combinations of the stiffness/texture properties and emotional states of the virtual face. Index numbers from 1−6 in Table 1 correspond to the six universal emotions used to generate random combinations (anger, fear, disgust, happiness, surprise, and sadness emotion, respectively). To avoid carryover effects, the 24 tasks were ordered by considering counterbalancing.

4 Results

4.1 Responses to watching emotional face

To understand how participants were emotionally influenced by watching the virtual face with the six basic emotions, we analyzed their subjective ratings. A summary of all the results is shown in Table 2. The reported p-values in Table 2 are the outcome of the Wilcoxon signed rank test that were eventually corrected by Bonferroni method.

Our results suggested that watching an angry face in a virtual environment influenced anger in the viewer ($p < 0.01$). This result was also cross-validated with valence ratings ($p < 0.01$). These findings are in agreement with previous studies about how watching an angry face may induce anger in the real world (Dimberg and Söderkvist 2011; Pell and

Table 2 Emotional responses when participants viewed emotional faces (reported ratings are corrected based on emotional responses when viewing neutral model for each participant).

Emotional	Facial model						
Responses		Anger	Fear	Disgust	Happiness	Surprise	Sadness
Anger	M	14.2	0.7	4	1	0.3	0.9
	SD	19.3	2.6	14.8	10	7	7.5
	p	0.0039**	1.0000	1.0000	1.0000	1.0000	1.0000
Fear	M	12.8	1.6	− 3	− 8.7	− 5.9	− 7.8
	SD	21.7	23.7	21.6	16.8	19.6	17.4
	p	0.0845	1.0000	1.0000	0.0938	1.0000	0.2734
Disgust	M	10	2.2	11.2	− 0.6	− 2.6	− 2.4
	SD	18.4	10.1	23.3	17.1	9.2	11.1
	p	0.0508	1.0000	0.0966	1.0000	1.0000	1.0000
Happiness	M	− 8	3.1	− 8.4	23.3	4.9	− 8.8
	SD	16.7	23.4	18.2	19.6	23.4	17.8
	p	0.1250	1.0000	0.1875	0.0012**	1.0000	0.1250
Surprise	M	7.4	18.3	− 6.3	− 1.7	21.3	− 9.1
	SD	19.6	27.3	16.2	18.4	32.8	16.5
	p	0.6972	0.0331*	0.4448	1.0000	0.0486*	0.0400*
Sadness	M	1.5	− 3.1	8.4	− 1.7	− 3.4	26.7
	SD	10.5	8.3	19.6	10.9	8.1	22.9
	p	1.0000	1.0000	0.3594	1.000	1.0000	0.0002**
Valence	M	− 36.2	− 9.8	− 30.9	22	− 3.8	− 28
	SD	39.9	44.4	41.2	41.7	35.2	39.9
	p	0.0009**	1.0000	0.0074**	0.0685	1.0000	0.0250*
Arousal	M	7.6	11	− 8.7	13.1	15.8	− 4.5
	SD	39.9	44.9	28	30.1	38.8	40.8
	p	1.0000	1.0000	1.0000	0.3078	0.3498	1.0000

Wilcoxon signed rank test corrected by Bonferroni, $*p < 0.05$,$**p < 0.01$

Table 3 Relative change in the participants' emotional responses while touching emotional faces for the four haptic conditions compared to the case when watching the respective emotional face. Wilcoxon rank-sum test corrected by Bonferroni, *$p < 0.05$

Emotional	Facial model						
Responses		Anger	Fear	Disgust	Happiness	Surprise	Sadness
Anger	M	9.6	1.0	7.7	− 1.5	0.5	1.8
	SD	28.5	7.8	18.2	8.1	8.2	9.7
	p	1.0000	1.0000	0.0707	1.0000	1.0000	1.0000
Fear	M	− 8.1	− 2.4	1.2	− 0.2	6.3	1.2
	SD	19.4	22.7	15.4	8.2	19.6	10.5
	p	0.5807	1.0000	1.0000	1.0000	1.0000	1.0000
Disgust	M	0.3	1.8	2.1	2.7	5.5	3.4
	SD	24.8	15.8	23.7	14.2	16.2	13.3
	p	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Happiness	M	0.4	− 6.0	0.1	− 2.4	− 8.3	0.9
	SD	6.7	18.5	4.5	20.9	17.3	4.3
	p	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Surprise	M	− 12.8	− 10.8	0.8	− 5.2	− 8.7	0.0
	SD	19.1	25.8	13.2	14.2	26.1	10.9
	p	*0.0215	0.4843	1.0000	1.0000	1.0000	1.0000
Sadness	M	− 0.9	2.0	− 4.0	− 1.5	2.4	− 0.9
	SD	12.2	7.1	19.7	6.6	8.5	21.0
	p	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Valence	M	− 4.7	− 2.3	− 0.5	− 8.1	− 10.1	6.7
	SD	49.1	35.4	34.4	39.6	34.8	27.0
	p	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Arousal	M	− 7.4	− 6.4	6.7	− 6.5	− 9.5	− 1.4
	SD	44.9	35.3	37.0	30.6	31.7	30.2
	p	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

Richards 2011). On the other hand, fear facial expressions, which were confused with surprise as shown in Sect. 3.2, resulted in a significant increase in surprise ($p < 0.05$) but not fear. This is also observed in previous research (Flack et al. 1999). Viewing disgusted model resulted in a significant decrease in valence ratings ($p < 0.01$). This confirms a phenomenon known as the valence intensity effect which describes how humans are sensitive to valence intensity in negative emotional stimuli but not in positive ones (Lu et al. 2016). Happy facial expressions affected happiness in the viewers ($p < 0.01$). This is in line with previous research findings about the fact that watching a happy face induces happiness in the viewer in the real world (Deng and Hu 2017). Surprise facial expressions influenced surprise responses in the viewer ($p < 0.05$). This is also confirmed in previous studies (Lewis 2012). Finally, sad facial expressions resulted in a significant increase in sadness ($p < 0.01$) and a significant decrease in surprise responses ($p < 0.05$). These results were also cross-validated with a significant decrease in valence rating ($p < 0.05$), and are similar to those reported in previous studies (Flack et al. 1999). With previous studies showing how watching emotional face influences the viewer's emotional responses in the real world, similar findings are confirmed in this study for watching an emotional face in a virtual environment.

4.2 Responses to touching emotional face

To evaluate the emotional responses in individuals' while touching emotional faces bearing different haptic properties (texture and stiffness), participants' subjective ratings submitted after each haptic interaction were analyzed. Ratings were adjusted for the base line case when participants were asked to rate their initial emotional responses by watching the neutral model.

The results for the emotional responses due to touching emotional face displaying the six basic emotions are shown in Table 3. The mean and standard deviation for the differences in emotional responses between touching and watching the emotional faces are presented. Moreover, *p*-values from Wilcoxon rank-sum test for all the emotions are reported. It is noted that a significant decrease in the surprise level among participants was found when they touched the angry model compared to the case when they just watched it (Wilcoxon rank-sum test, $p < 0.05$, corrected by Bonferroni). Figure 4 shows how the basic emotional ratings are influenced by touching the emotional faces compared to watching it. In case of touching, the

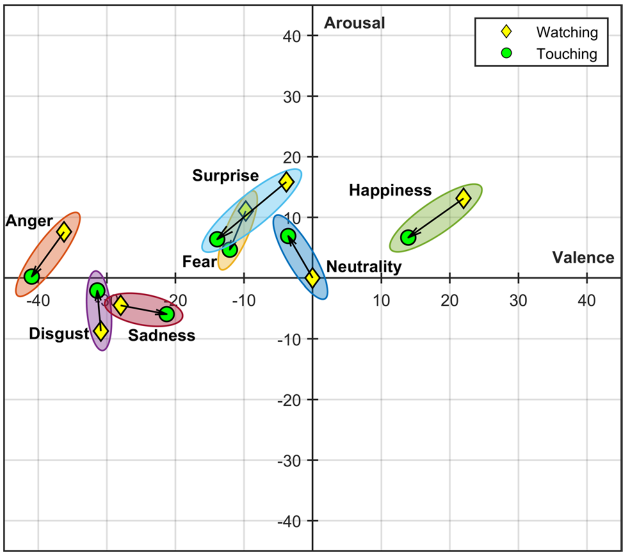

Fig. 4 Participants' change in emotional responses (mean valence and arousal levels) when they watched the facial models compared to the case when they touched the facial models with respective emotions (reported ratings are baseline adjusted)

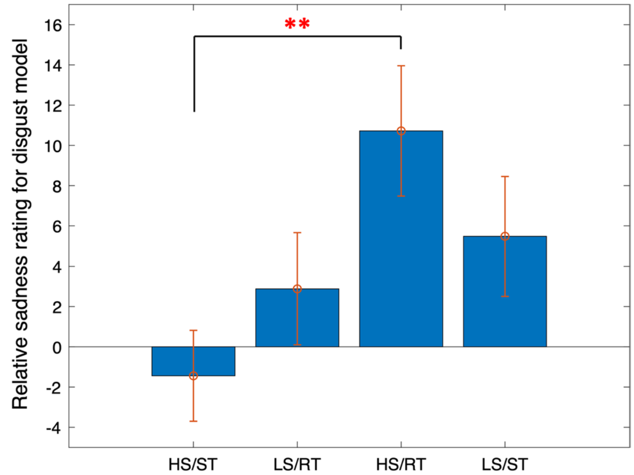

Fig. 5 Participants' relative sadness level to watching neutral face in case of touching disgust face with four types of haptic properties. HS/ST, LS/RT, HS/RT, and LS/ST indicate high stiffness/smooth texture, low stiffness/rough texture, high stiffness/rough texture, and low stiffness/smooth texture, respectively. Kruskal–Wallis test, $^{**}p < 0.01$; Ad hoc, Bonferroni correction

valence ratings for the happiness, surprise, and anger expressions decreased, while the valence ratings for sadness expression increased. Touching the angry, happy, surprise, and fear facial models resulted in a decrease in the arousal ratings, while neutrality and disgust expressions resulted in an increase in the arousal ratings.

Furthermore, the effects of physical properties on emotional responses while touching the emotional face were also examined. Our results suggested that the physical properties of the touched model play a considerable role in modulating emotions in the toucher. Table 4 reports the p-values for the significance of emotional responses while touching facial models based on physical properties. It is clear that the effects of physical properties were significant to modulate sadness while touching a disgusted face (Table 4). Examining the differences between physical properties, Fig. 5 shows a significant increase in sadness rating when touching the disgusted model with high stiffness/rough texture compared to touching the disgusted model with high stiffness/smooth texture (Kruskal–Wallis test, $p < 0.01$; Ad hoc, Bonferroni correction). Previous research has demonstrated that rough texture experiences are usually judged more negatively than smooth surfaces (Ollivier et al. 2019). Furthermore, previous research showed that touching a hard object (high stiffness) influences positive feelings (valence) of the toucher (Ravaja et al. 2017). It seems the combination of rough texture and hardness further modulated negative feelings in the form of sadness.

5 Discussion

5.1 Emotional responses to emotional face

Along the lines of earlier research for watching emotional face in the physical world (Aviezer et al. 2008; Dailey et al. 2002; Susskind et al. 2007; Smith and Scott 1997, our results supported the notion that watching an emotional face influences emotions of the viewer in a virtual environment. This was particularly true for anger, happiness, surprise, and sadness. Happiness and sadness are the most representative positive and negative emotions, which seem to have the strongest effect on the participants' emotional responses. Anger and disgust facial expressions also resulted in significant increase in anger and disgust levels, respectively. It is presumed that negative facial expressions had a stronger stimulation than their positive counterparts (Baumeister et al. 2001), thus creating stronger emotional responses. These results were cross-validated with valence/arousal ratings.

An interesting finding was that when participants viewed the virtual face displaying fear, there was no significant increase in the fear level, rather a significant increase in the surprise level. Fear has been described as negatively valenced surprise (Vrticka et al. 2014) (fear indicates a potential threat whereas surprise conveys a sense of novelty or unexpectedness (Schroeder et al. 2004)). Therefore, this

Table 4 *p* values for emotional responses based on the physical properties of the touched emotional face. Kruskal–Wallis test corrected by Bonferroni, ** $p < 0.01$

Emotional	Facial model					
Responses	Anger	Fear	Disgust	Happiness	Surprise	Sadness
Anger	0.8996	0.1765	0.8894	0.6732	0.4648	0.8435
Fear	0.9839	0.8679	0.9676	0.9987	0.5868	0.7479
Disgust	0.7506	0.8576	0.4158	0.5121	0.8616	0.6125
Happiness	0.9221	0.7920	0.9384	0.6444	0.7228	0.8630
Surprise	0.8166	0.7677	0.2801	0.7000	0.8904	0.9351
Sadness	0.6168	0.9323	0.0077**	1.0000	0.9342	0.9486
Valence	0.8111	0.7800	0.5843	0.6240	0.7049	0.8804
Arousal	0.7416	0.2069	0.8325	0.7467	0.7506	0.9046

result seems valid because humans do not expect others to be afraid when the source of threat is unknown.

Watching the virtual face with anger facial expressions significantly increased the anger level. These results confirm that negative images have a deeper influence on people. This is again in line with the valence intensity effect which describes how humans are sensitive to valence intensity in negative emotional stimuli but not in positive ones (Lu et al. 2016). Another unexpected result was that watching the virtual face with sad facial expressions significantly reduced the surprise level. This could probably be explained by previous findings that sad facial expressions are better recognized (and thus more familiar) when expressed by virtual faces than human faces (Dyck et al. 2008). Therefore, watching a familiar facial expression (sadness in this case) resulted in a reduced surprise response.

The present findings suggest that touching emotional face modulates emotional responses in the toucher. For instance, statistically significant reduction in surprise level was reported while touching an angry face regardless of the specific haptic properties of the touched face. As for the effects of physical properties, it was shown that the high stiffness/rough texture condition resulted in a significant increase in sadness compared to the high stiffness/smooth texture condition. It is assumed that a combination of hard and smooth sensation comforted the touching person by reducing sadness (Singh et al. 2014). These findings provide insight into the relationship between physical properties of material and the emotional responses in the toucher.

5.2 Contextual bias

Previous research has shown that facial expressions of emotions are experienced in a wider context, including body language, the ambient environment, and viewers' beliefs and expectations (Gescheider and Hughson 1991; Calbi et al. 2017). For instance, many participants' perceived anger and disgust expressions interchangeably (Appendix 1), which is also confirmed in previous studies (Aviezer et al. 2008; Dailey et al. 2002; Susskind et al. 2007; Smith and Scott 1997. Similarly, surprise was confused with fear as in agreement with previous studies with an argument that surprise emotion is a cognitive state that combines with true, valenced emotions such as fear or happiness (Etcoff and Magee 1992; Ekman 1984; Oatley and Johnson-Laird 1987).

Participants' rated their emotional responses differently along the six basic emotions and the valence/ arousal space with or without haptic interactions (Table 2, 3 and Fig. 4). Touching an emotional face might create another contextual bias (Gescheider and Hughson 1991; Calbi et al. 2017, and this is also visible in the reported emotional responses by the participants. As shown in Fig. 4, the participants' emotional responses to the six basic facial models are at a different location on a valence/arousal space than reported in the circumplex model of affect (Russell 1980; Posner et al. 2005. Since the terminologies valence and arousal were unfamiliar to non-experts, we replaced them with the unpleasant/pleasant and deactivated/activated in the response interface GUI (Fig. 1). Nevertheless, many participants reported after the experiment that expressing their feelings on this scale was unfamiliar and uncomfortable. It is assumed that these may have resulted in the distortion of circumplex model of affect. These observations highlight the importance of studying emotional responses under ecologically valid conditions.

5.3 Study limitations

Although the findings of the present study were supported by statistical significance, a few limitations should be mentioned. First, the current study relied on self-reporting to measure perceived and emotional responses rather than psycho-physiological measures. Self-reporting measures the subjective experience of emotions and thus can be inconsistent, unreliable, and difficult to reproduce (Seeley et al. 2015). Another limitation is the use of static emotional faces, other attributes such as gender or facial expressions animation, are expected to further modulate emotional responses. Finally, the current study did not consider any interaction with the emotional faces, which would largely influence the emotional responses. This could be an interesting direction for future research.

6 Conclusion

In this study, the effects of viewing and touching a virtual emotional face on modulating emotional responses in the viewer/toucher were examined. It is evident that viewing emotional face in a virtual environment influences emotions in the viewer. The same applies to touching emotional face where touching an angry face significantly reduced the surprise levels in the toucher. Furthermore, it was found that physical properties play a noticeable role in modulating emotional responses in the toucher.

As for future work, we plan to examine the effects of physical properties in interpersonal communication in virtual environments, for both the touching and the touched parties. Furthermore, we would like to study the effects of multi-modal interaction (haptic-visual-auditory) as this would resemble real human-to-human interaction. Finally, an interesting future direction would be to utilize physiological data to measure emotional responses rather than relying on the self-reporting mechanism.

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Compliance with ethical standards

Conflicts of interest The authors declare to have no conflicts of interest.

Ethical standards The current research was approved by New York University Abu Dhabi's local Ethics Committee (IRB # 062-2018).

A: Perceived emotions

(See Table 5)

Table 5 Relative rating scores for perceived emotions when participant's watch six basic emotions from the case when watching neutral face. Wilcoxon signed rank test corrected by Bonferroni, $^{**}p < 0.01$, $^{***}p < 0.001$

Perceived Emotion	Facial Model	Anger	Fear	Disgust	Happiness	Surprise	Sadness
Anger	M	84.9	16.0	44.3	− 0.8	− 0.8	0.1
	SD	16.1	33.2	23.8	3.1	3.1	0.5
	p	0.0005***	1.0000	0.1250	1.0000	1.0000	1.0000
Fear	M	− 0.9	56.7	0.0	0.5	14.5	4.1
	SD	3.6	31.8	5.3	6.2	23.3	14.2
	p	1.0000	0.0020**	0.7500	1.0000	0.0078**	1.0000
Disgust	M	19.3	11.1	40.0	4.3	2.7	4.9
	SD	29.8	19.3	32.1	8.6	8.4	13.2
	p	0.0010***	1.0000	0.0039**	1.0000	1.0000	1.0000
Happiness	M	0.0	4.1	0.0	35.2	1.6	0.0
	SD	0.0	16.0	0.0	23.7	6.2	0.0
	p	1.0000	1.0000	1.0000	0.0005***	1.0000	1.0000
Surprise	M	0.0	45.6	0.8	0.0	79.1	0.0
	SD	0.0	35.3	3.1	0.0	16.6	0.0
	p	1.0000	0.1250	1.0000	1.0000	0.0005***	1.0000
Sadness	M	− 14.8	− 14.8	− 11.3	− 11.7	− 10.9	40.1
	SD	22.7	22.7	24.3	24.0	27.4	22.0
	p	0.5000	1.0000	0.5000	0.5000	0.5000	0.0005***
Valence	M	− 46.0	− 18.0	− 40.4	16.0	− 0.5	− 21.7
	SD	38.9	49.4	36.1	27.1	34.8	26.8
	p	0.0020**	0.8594	0.0098**	0.4805	1.0000	0.0742
Arousal	M	− 5.6	9.6	− 5.7	24.7	25.3	− 6.4
	SD	46.3	49.5	48.0	38.8	50.3	29.2
	p	1.0000	1.0000	1.0000	0.1211	0.5391	1.0000

References

Abdi H (2010) Holm's sequential Bonferroni procedure. Encycl Res Des 1(8):1–8

Aviezer H, Hassin RR, Ryan J, Grady C, Susskind J, Anderson A, Moscovitch M, Bentin S (2008) Angry, disgusted, or afraid? studies on the malleability of emotion perception. Psychol Sci 19(7):724–732

Barnes CJ, Childs THC, Henson B, Southee CH (2007) Surface finish and touch—a case study in a new human factors tribology. Wear 257:740–750

Baumeister RF, Bratslavsky E, Finkenauer C, Vohs KD (2001) Bad is stronger than good. Rev Gen Psychol 5(4):323

Bernal G, Maes P (2017) Emotional beasts: visually expressing emotions through avatars in vr. In: Proceedings of the 2017 CHI conference extended abstracts on human factors in computing systems, pp 2395–2402

Bhatta S, Tiippana K, Vahtikari K, Hughes M, Kyttä M (2017) Exploring relationships between touch perception and surface physical properties. Front Psychol 8:367

Calbi M, Heimann K, Barratt D, Siri F, Umiltà MA, Gallese V (2017) How context influences our perception of emotional faces: a behavioral study on the kuleshov effect. Front Psychol 8:1684

Cardello AV, Winterhalter C, Schutz HG (2003) Predicting the handle and comfort of military clothing fabrics from sensory and instrumental data: development and application of new psychophysical methods. Text Res J 73(3):221–237

Chen X, Shao F, Barnes C, Childs T, Henson B (2009) Exploring relationships between touch perception and surface physical properties. Int J Des 3(2):67–76

Childs THC, Henson B (2007) Human tactile perception of screen-printed surfaces: self-report and contact mechanics experiments. J Eng Tribol 221(3):421–441

Dailey MN, Cottrell GW, Padgett C, Adolphs R (2002) Empath: a neural network that categorizes facial expressions. J Cogn Neurosci 14(8):1158–1173

Deng H, Hu P (2017) Matching your face or appraising the situation: two paths to emotional contagion. Front Psychol 8:2278

Dimberg U, Söderkvist S (2011) The voluntary facial action technique: a method to test the facial feedback hypothesis. J Nonverbal Behav 35(1):17–33

Dyck M, Winbeck M, Leiberg S, Chen Y, Gur RC, Mathiak K (2008) Recognition profile of emotions in natural and virtual faces. PLoS ONE 3(11):e3628

Eid MA, Osman HA (2016) Affective haptics: current research and future directions. IEEE Access 4:26–40

Ekman P (1984) Expression and the nature of emotion. Approaches Emot 3:19–344

Ekman P (1992) Are there basic emotions? Psychol Rev 99(3):550–553

Ekman P, Friesen WV, O'sullivan M, Chan A, Diacoyanni-Tarlatzis I, Heider K, Krause R, LeCompte WA, Pitcairn T, Ricci-Bitti PE, et al (1987) Universals and cultural differences in the judgments of facial expressions of emotion. J Personal Soc Psychol 53(4):712

Essick GK, McGlone F, Dancer C, Fabricant D, Ragin Y, Phillips N, Jones T, Guest S (2010) Quantitative assessment of pleasant touch. Neurosci Biobehav Rev 34(2):192–203

Etcoff NL, Magee JJ (1992) Categorical perception of facial expressions. Cognition 44(3):227–240

Flack WF Jr, Laird JD, Cavallaro LA (1999) Separate and combined effects of facial expressions and bodily postures on emotional feelings. Eur J Soc Psychol 29(2–3):203–217

Friesen E, Ekman P (1978) Facial action coding system: a technique for the measurement of facial movement. Palo Alto 3,

Gescheider GA, Hughson BA (1991) Stimulus context and absolute magnitude estimation: a study of individual differences. Percept Psychophys 50(1):45–57

Hatfield E, Cacioppo JT, Rapson RL (1993) Emotional contagion. Curr Dir Psychol Sci 2(3):96–100

Hess U, Fischer A (2013) Emotional mimicry as social regulation. Personal Soc Psychol Rev 17(2):142–157

Holliins M, Faldowski R, Rao S, Young F (1993) Perceptual dimensions of tactile surface texture: a multidimensional scaling analysis. Percept Psychophys 54(6):697–705

Israr A, Abnousi F (2018) Towards pleasant touch: vibrotactile grids for social touch interactions. In: Extended abstracts of the 2018 CHI conference on human factors in computing systems, pp 1–6

Klatzky RL, Lederman SJ (2002) Touch. In Healy AF, Proctor RW (Eds) Experimental psychology, pp 147–176

Klinger E, Bouchard S, Légeron P, Roy S, Lauer F, Chemin I, Nugues P (2005) Virtual reality therapy versus cognitive behavior therapy for social phobia: A preliminary controlled study. Cyberpsychol Behav 8(1):76–88

Ko BC (2018) A brief review of facial emotion recognition based on visual information. Sensors 18(2):401

Kret ME, Roelofs K, Stekelenburg JJ, de Gelder B (2013) Emotional signals from faces, bodies and scenes influence observers' face expressions, fixations and pupil-size. Front Hum Neurosci 7(1):810

Lane RD, Chua PM, Dolan RJ (1999) Common effects of emotional valence, arousal and attention on neural activation during visual processing of pictures. Neuropsychologia 37(9):989–997

Lawrence-Wood ER (2011) Trust me, this is (n't) scary!: How trust affects social emotional influence in threatening situations. Flinders University of South Australia, School of Psychology

Lederman SJ, Klatzky RL (2007) Special issue: new directions in touch. Can J Exp Psychol 61(3):169–275

Lederman SJ, Klatzky RL, Abramowicz A, Salsman K, Kitada R, Hamilton C (2007) Haptic recognition of static and dynamic expressions of emotion in the live face. Psychol Sci 18(2):158–164

Lederman SJ, Klatzky RL, Rennert-May E, Lee J, Ng K, Hamilton C (2008) Haptic processing of facial expressions of emotion in 2d raised-line drawings. IEEE Trans Haptics 1(1):27–38

Lewis MB (2012) Exploring the positive and negative implications of facial feedback. Emotion 12(4):852

Löken LS, Wessberg J, McGlone F, Olausson H (2009) Coding of pleasant touch by unmyelinated afferents in humans. Nat Neurosci 12(5):547

Lu Y, Luo Y, Lei Y, Jaquess KJ, Zhou C, Li H (2016) Decomposing valence intensity effects in disgusting and fearful stimuli: an event-related potential study. Soc Neurosci 11(6):618–626

Marcus G, Neuman W, MacKuen M (2015) Measuring emotional response: comparing alternative approaches to measurement. Political Sci Res Methods 5(4):733–754

Min YK, Chung SC, Min BC (2005) Physiological evaluation on emotional change induced by imagination. Appl Psychophysiol Biofeedback 30(2):137–150

Mumenthaler C, Sander D (2015) Automatic integration of social information in emotion recognition. J Exp Psychol Gen 144(2):392

Nagano H, Okamoto S, Yamada Y (2013) Visual and sensory properties of textures that appeal to human touch. Int J Affect Eng 12(3):375–384

Oatley K, Johnson-Laird PN (1987) Towards a cognitive theory of emotions. Cogn Emotion 1(1):29–50

Okamoto S, Nagano H, Yamada Y (2012) Psychophysical dimensions of tactile perception of textures. IEEE Trans Haptics 6(1):81–93

Ollivier R, Goupil L, Liuni M, Aucouturier JJ (2019) Enjoy the violence: Is appreciation for extreme music the result of cognitive

control over the threat response system? Music Percept Interdiscip J 37(2):95–110
Parkinson B, Simons G (2009) Affecting others: social appraisal and emotion contagion in everyday decision making. Personal Soc Psychol Bull 35(8):1071–1084
Pell PJ, Richards A (2011) Cross-emotion facial expression aftereffects. Vis Res 51(17):1889–1896
Peters K, Kashima Y (2015) A multimodal theory of affect diffusion. Psychol Bull 141(5):966
Posner J, Russell JA, Peterson BS (2005) The circumplex model of affect: an integrative approach to affective neuroscience, cognitive development, and psychopathology. Develop Psychopathol 17(3):715
Ravaja N, Harjunen V, Ahmed I, Jacucci G, Spapé MM (2017) Feeling touched: emotional modulation of somatosensory potentials to interpersonal touch. Sci Rep 7(1):1–11
Riva G, Mantovani F, Capideville CS, Preziosa A, Morganti F, Villani D, Gaggioli A, Botella C, Alcañiz M (2007) Affective interactions using virtual reality: the link between presence and emotions. CyberPsychol Behav 10(1):45–56
Russell JA (1980) A circumplex model of affect. J Personal Soc Psychol 39(6):1161
Schroeder U, Hennenlotter A, Erhard P, Haslinger B, Stahl R, Lange KW, Ceballos-Baumann AO (2004) Functional neuroanatomy of perceiving surprised faces. Human Brain Mapp 23(4):181–187
Seeley SH, Garcia E, Mennin DS (2015) Recent advances in laboratory assessment of emotion regulation. Curr Opin Psychol 3:58–63
Singh H, Bauer M, Chowanski W, Sui Y, Atkinson D, Baurley S, Fry M, Evans J, Bianchi-Berthouze N (2014) The brain's response to pleasant touch: an eeg investigation of tactile caressing. Front Hum Neurosci 8:893
Smith C, Scott H (1997) A componential approach to the meaning of facial expressions. The psychology of facial expression 229,
Susskind J, Littlewort G, Bartlett M, Movellan J, Anderson A (2007) Human and computer recognition of facial expressions of emotion. Neuropsychologia 45(1):152–162
Vrticka P, Lordier L, Bediou B, Sander D (2014) Human amygdala response to dynamic facial expressions of positive and negative surprise. Emotion 14(1):161
Yohanan S, MacLean KE (2012) The role of affective touch in human-robot interaction: Human intent and expectations in touching the haptic creature. Int J Soc Robot 4(2):163–180
Zhao K, Yan WJ, Chen YH, Zuo XN, Fu X (2013) Amygdala volume predicts inter-individual differences in fearful face recognition. PLoS ONE 8(8):e74096. https://doi.org/10.1371/journal.pone.0074096