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Sociality of facial expressions in immersive virtual environments: A facial EMG study

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ABSTRACT

Immersive virtual environment technology is increasingly used by psychologists as a tool for researching social influence in realistic, yet experimentally controllable, settings. The present study demonstrates the validity and reliability of facial electromyography as a marker of affect in immersive virtual environments and further shows that the mere presence of virtual humans is enough to elicit sociality effects on facial expressiveness. Participants viewed pleasant and unpleasant images in a virtual room either alone or with two virtual humans present. The patterns of smiling and frowning activity elicited by positive and negative stimuli in the virtual environment were the same as those found in laboratory settings. Moreover, when viewing positive stimuli, smiling activity was greater when two agents were present than in the alone condition. The results provide new psychophysiological evidence for the potency of social agents in immersive virtual environments.

1. Introduction

Immersive virtual environment (IVE) technology is increasingly used by psychologists as a tool for understanding human behavior in realistic, yet experimentally controllable, settings (see Fox et al., 2009; McCall and Blascovich, 2009, for reviews of IVE use in behavioral research). The immersive visual experience is often conveyed to participants through a head-mounted display (HMD) that uses head movements to adjust the visual display of the environment in real-time, permitting visual and physical exploration of a three-dimensional, computer-simulated environment as though it were real. The immersive world instills a sense of presence in the user – a feeling that the user exists in the virtual environment (rather than merely watching it); the IVE is capable of portraying psychologically realistic scenarios (e.g., Kotlyar et al., 2008) and socially potent computer-controlled virtual humans (i.e., *agents*; Bailenson et al., 2001). The present study extends what is known about the social potency of agents by testing the effects of the apparent "company" of virtual others on facial expressiveness through electromyography (EMG).

The social potency of IVEs has been demonstrated with a variety of methodologies. For example, the amount of interpersonal space an immersed participant grants to an agent can be augmented by having the agent engage in eye contact (Bailenson et al., 2003) or by altering the ethnic appearance of the agent (Dotsch and Wigboldus, 2008; McCall et al., 2009). On the basis of such findings, Blascovich et al. (2002) proposed a threshold model of social influence with IVEs. Whether an agent will influence the participant's behavior depends on four variables: *behavioral realism* (the extent to which the agent behaves like its real-world counterpart), *social presence* (the degree to which the participant believes the agent is under the control of an actual human), *self-relevance* (the extent to which the interaction has value or meaning to the participant), and *the target response system* (the level of the behavioral response – automatic and low-level vs. more controlled and high-level). According to the model, virtual humans are more likely to have an impact on the participant's behavior as each of these variables increases. For example, when a participant believes the agent is controlled by another person, and the agent's behavior and appearance closely approximates real human behavior, the participant should interact with the agent much like he or she would in the real world.

An aim of the present study was to examine the extent to which such agents in an IVE can influence a low-level behavior: spontaneous facial expressions. Facial expressions can serve as automatic markers of an affective state. Consistent with this interpretation, pleasant stimuli reliably potentiate smiling (i.e., zygomaticus major activity) and inhibit frowning (i.e., corrugator supercilii activity) expressions (see Tassinary et al., 2007, for a review). Yet, the correspondence between affective states and facial muscle activity varies considerably across individuals (Larsen et al., 2003) and social contexts. For instance, the perceived presence of

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other humans intensifies smiling toward pleasant stimuli (i.e., the "sociality effect;" Fridlund, 1991). This sociality effect on smiling is strongest when a social other is physically present, yet the implied presence of social others, such as knowing that a friend is viewing the same material in another room, is sufficient to elicit exaggerated expressions to positive stimuli (Fridlund, 1991; Hess et al., 1995). It is unclear, however, whether agents can also elicit the sociality effect, particularly when social presence and self-relevance are low.

Prior research has demonstrated that depictions of virtual humans can influence facial muscle movements, even when participants are not immersed in an IVE. Consistent with the Blascovich et al. (2002) threshold model of social influence, simply viewing the facial expression of a dynamic avatar[1] (i.e., one with higher behavioral realism) on a computer screen elicits more mimicry than a static avatar (i.e., one with low behavioral realism) as measured by facial EMG (Weyers et al., 2006). In addition, when self-relevance is increased by nonconsciously priming social competition, facial mimicry when viewing happy and sad avatar faces while playing a live online game becomes counter-empathic (Weyers et al., 2009). Such unconscious nonverbal behaviors suggest that agents trigger automatic, reactive goals within us (Bargh and Chartrand, 1999). To date, however, no study has examined the sociality effect in a virtual environment.

Building on this prior research, the present study examined the effects of agents in an IVE on two distinct automatic functions of facial expressions within a virtual environment: expressions as affective markers and expressions as social signals. A fuller understanding of such effects would help establish the pervasiveness of the sociality effect – that is, perhaps we are so used to modifying our facial expressions in the presence of other humans, we automatically do so at the slightest suggestion in a virtual environment. In addition, because facial EMG has been a useful measure of affect in other contexts, demonstrating that it is a valid marker of affect in response to variables manipulated in an IVE would mean that researchers would have another noninvasive measure to add to their methodological armamentarium.

Participants wore a stereoscopic HMD while facial EMG was recorded from the brow and cheek regions. First, we examined whether facial expressiveness in an IVE is affected by affective visual stimuli in the same manner as in previous laboratory settings. We hypothesized that pleasant and unpleasant visual stimuli would elicit greater zygomaticus and corrugator activity, respectively. Second, we tested whether the mere presence of social agents in an immersive virtual environment is sufficient to elicit exaggerated facial expressions when viewing pleasant stimuli. We provided no information about the agents. That is, social presence was low, as participants did not believe the agents were controlled by actual humans, and self-relevance was also low because the agents had no ostensible connection to the participant. Given the low-level response of facial activity, however, we hypothesized that zygomaticus activity would be potentiated for positive stimuli when these nominally social agents were present in the virtual environment, similar to when a friend was present in the earlier studies of sociality effects (Fridlund, 1991; Hess et al., 1995). In addition, we examined whether sociality effects would occur for unpleasant stimuli and whether corrugator activity was similarly affected by social cues, as such sociality effects have not been previously demonstrated for negative stimuli.

[1] Although the stimuli in these studies better conformed to Blascovich et al.'s (2002) definition of agents (i.e., computer-controlled virtual humans) rather than avatar (i.e., a virtual human controlled by real human), we use the term avatar to be consistent with the respective studies' terminology.

2. Method

2.1. Participants

Forty-nine university students (23 women, 26 men) were recruited from an introductory psychology course in the United States and received course credit for participation. Participants were between the ages of 18 and 30 years ($M = 21.5$; $SD = 2.4$).

2.2. Stimuli

Forty stimulus pictures were chosen from the International Affective Picture System (IAPS; Lang et al., 1999) according to normalized valence ratings provided with the set. One half of the pictures (the "positive" stimuli) were selected for their high pleasantness ratings[2] ($M = 8.04$, $SD = 0.17$) and the remaining pictures (the "negative" stimuli) were selected for their low pleasantness ratings[3] ($M = 2.25$, $SD = 0.17$), $t(38) = 109.85$, $p < .001$. Positive and negative pictures were matched for arousal based on the ratings that accompany the IAPS set. Pictures depicting gore, mutilations, and nudity were not included.

Each session used one of two pseudo-randomized orders to present the stimuli. Each order was randomized and then adjusted to minimize consecutive presentations of stimuli from the same valence set to a maximum of two.

2.3. Procedure

Participants were seated in a comfortable chair. Bipolar EMG was recorded over the right eyebrow and cheek regions, targeting the corrugator supercilii and the zygomaticus major muscles, respectively (Fridlund and Cacioppo, 1986). A ground electrode was attached over the left forehead. The participant was then equipped with a stereoscopic head-mounted display (HMD; see Fig. 1a), which could be adjusted for comfort. The corrugator EMG electrodes were thus completely covered by the HMD device, and their wires ran under the cushion of the HMD. The Virtual Research V8 HMD uses dual 1.3 "diagonal active matrix liquid crystal displays to project a 640×480 resolution display to each eye giving the participant a 60° field of view in 3D vision. The HMD rendered a virtual room in which participants perceived themselves as seated.

Participants were instructed to look around the virtual room from their seated position before the study began. In front of the participant a movie screen hung in front of a white wall. When participants looked around the room, those in the co-viewing condition ($n = 23$) could see two human-looking agents in brown chairs seated slightly forward and to either side of their own position; the agents remained seated throughout the task (see Fig. 1b). For participants in the alone condition ($n = 26$) the two brown chairs were empty.

Participants were told that they would watch a slide show on the screen in front of them and rate each slide (i.e., IAPS image) after it was displayed. Before each picture, a fixation point was displayed in the center of the screen for 5 s. A 2-D picture was then displayed on the virtual screen for 5 s, which was then followed by a rating screen. The rating screen showed a scale with ratings 1 (*Bad*) to 5 (*Good*). Participants rated the affective valence of each slide using this scale. After participants viewed and rated all 40 pictures, the experimenter removed the HMD and the electrodes before debriefing and dismissing the participant.

2.4. Data reduction

A Biopac amplifier (Biopac Systems, Inc., Santa Barbara, CA) amplified signals from the EMG electrodes by a factor of 5000 and applied an online filter (0.1–500 Hz). EMG from both regions was recorded at 200 Hz[4] and stored for later scoring. Corrugator data for four participants (two from each condition) were not reduced further due to recording malfunctions; all zygomaticus data were retained.

Offline, data were filtered (band-pass 10–100 Hz, 60 Hz notch), digitally rectified, integrated with a constant of 50 samples. EMG data for each trial were segmented into a 1-s pre-stimulus epoch and a 4-s post-stimulus epoch. Magnitude change scores were calculated by dividing each 4-s epoch by the 1-s pre-stimulus epoch (van Boxtel, 2010). Due to positive skewness, the magnitude scores were then logarithmically transformed. An outlier analysis of mean baseline activity for each muscle revealed three participants with excessive zygomaticus baselines and two participants with excessive corrugator baselines. Those respective EMG channels were removed from further analyses for those participants.

[2] Pleasant IAPS images were 1440, 1460, 1610, 1710, 1750, 1920, 2040, 2050, 2057, 2070, 2080, 2150, 2260, 2340, 2530, 5760, 5830, 5910, 8190 and 8501.

[3] Unpleasant IAPS images were 2053, 2900, 3230, 3500, 6212, 6243, 6360, 6821, 7380, 9050, 9220, 9340, 9421, 9520, 9560, 9800, 9810, 9910, 9911, and 9921.

[4] The sampling rate was unusually low due to a software error. A small-scale replication of this study using a higher sampling rate (1000 Hz) found nearly the same pattern of results. Data from this small-scale replication was not included in this study because the replication was conducted in a different laboratory with a different HMD.

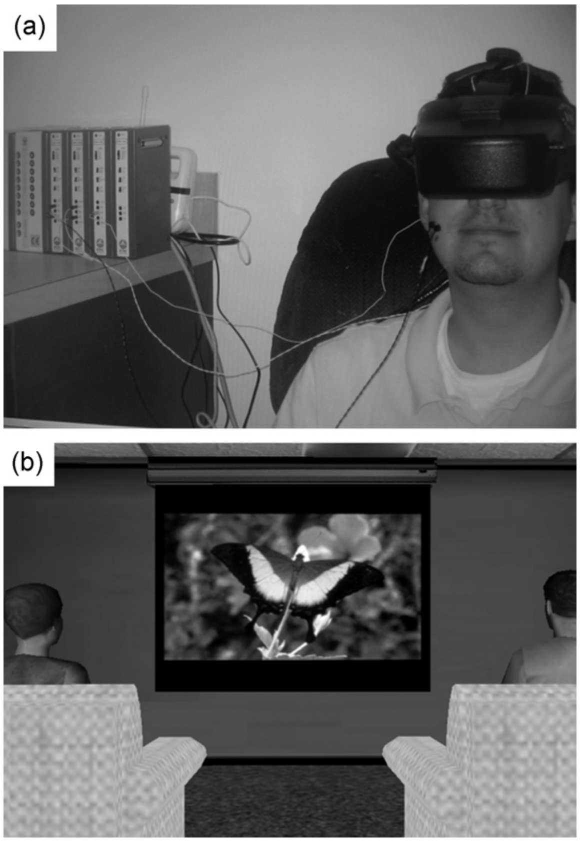

Fig. 1. (a) Facial EMG was recorded over the corrugator and zygomaticus areas while participants wore the head mounted display. (b) In the virtual room, participants rated pictures that appeared on a screen. In the co-view condition, two agents occupied the chairs in the virtual environment. In the alone condition, both chairs were empty.

3. Results

3.1. Self-report ratings

A two-way factorial Valence × Agent Presence repeated measures ANOVA revealed that Valence of the IAPS stimuli affected self-reported pleasantness of the stimuli, $F(1, 47) = 554.60$, $p < .001$, $\eta_p^2 = .922$, such that positive IAPS images ($M = 4.04$, 95% CI [3.82, 4.26]) were rated as more pleasant than negative IAPS images ($M = 1.49$, 95% CI [1.40, 1.57]). Agent Presence did not affect ratings either as a main effect, $F(1, 47) = 1.69$, $p = .20$, $\eta_p^2 = .035$, or as an interaction with Valence, $F(1, 47) = 0.16$, $p = .70$, $\eta_p^2 = .003$.

3.2. Facial EMG

The baseline corrected post-stimulus epochs for each trial were categorized based on the muscle region and stimulus valence. A test of multivariate outliers in the EMG data revealed two participants with Mahalanobis distances greater than 3 standard deviations from the mean of the distribution. Due to these extreme responses in both zygomaticus activity and corrugator, EMG data from these participants were excluded from further analyses. Complete EMG data remained for 42 participants ($n = 21$ alone condition), and partial EMG data remained for another 5 participants (1 zygomaticus alone, 1 zygomaticus co-viewing, 2 corrugator alone, 1 corrugator co-viewing). Baseline zygomaticus and corrugator activity were not affected by Agent Presence, $F(1, 40) = 0.67$, $p = .42$, $\eta_p^2 = .016$.

A three-way factorial Muscle × Valence × Agent Presence repeated measures ANOVA revealed significant main effects of

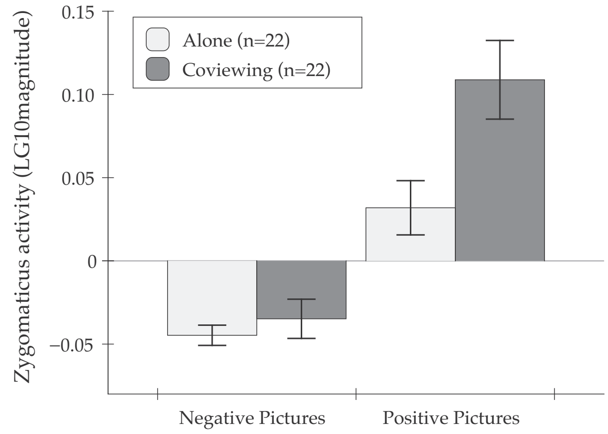

Fig. 2. Mean zygomaticus EMG activity as a function of Agent Presence and Valence of stimuli. Error bars represent 1 SEM.

Agent Presence, $F(1, 40) = 8.65$, $p < .01$, $\eta_p^2 = .819$, on post-stimulus EMG activity. The effect of Agent Presence was moderated by a significant Muscle × Agent Presence interaction, $F(1, 40) = 5.31$, $p = .03$, $\eta_p^2 = .613$, and a significant Muscle × Valence × Agent Presence interaction, $F(1, 40) = 6.59$, $p = .01$, $\eta_p^2 = .707$. A Muscle × Valence interaction confirmed that each muscle was differently sensitive to positive and negative stimuli, $F(1, 40) = 57.56$, $p < .001$, $\eta_p^2 = 1.000$. Separate analyses for each muscle further examine the influence of Agent Presence and Valence on facial expressions.

3.2.1. Zygomaticus major

A main effect of Valence, $F(1, 42) = 49.83$, $p < .001$, $\eta_p^2 = .543$, confirmed that zygomaticus activity was greater for positive stimuli than negative stimuli. A main effect for Agent Presence, $F(1, 42) = 7.37$, $p = .01$, $\eta_p^2 = .149$, revealed that post-stimulus zygomaticus activity was greater in the co-viewing condition. This was further qualified by a significant Valence × Agent Presence interaction, $F(1, 42) = 4.68$, $p = .04$, $\eta_p^2 = .100$ (see Fig. 2). Paired comparisons confirmed that zygomaticus activity for positive stimuli was greater in the co-viewing condition than the alone condition, $t(42) = 2.69$, $p = .01$. Zygomaticus activity for negative stimuli did not differ by Agent Presence condition, $t(42) = 0.74$, $p = .46$.

3.2.2. Corrugator supercilii

A main effect of Valence, $F(1, 43) = 43.06$, $p < .001$, $\eta_p^2 = .500$, confirmed that corrugator activity was greater for negative stimuli than positive stimuli. No main effect of Agent Presence was found, $F(1, 43) = 0.02$, $p = .89$, $\eta_p^2 < .001$; however, there was a marginally significant Valence × Agent Presence interaction, $F(1, 43) = 2.88$, $p = .10$, $\eta_p^2 = .063$ (see Fig. 3).

4. Discussion

As expected, across both agent presence conditions participants responded to positive and negative visual stimuli in a manner consistent with previous studies (e.g., Fridlund, 1991; Larsen et al., 2003). Negative pictures elicited lower pleasantness ratings, greater corrugator activity, and reduced zygomaticus activity, whereas positive pictures elicited higher pleasantness ratings, greater zygomaticus activity, and reduced corrugator activity. The HMD did not appear to interfere with the recording of facial EMG in any way, even though it completely enclosed the electrodes recording corrugator activity.

The results also confirmed our hypothesis regarding the effects of the agents' presence on zygomaticus region activity. Specifically,

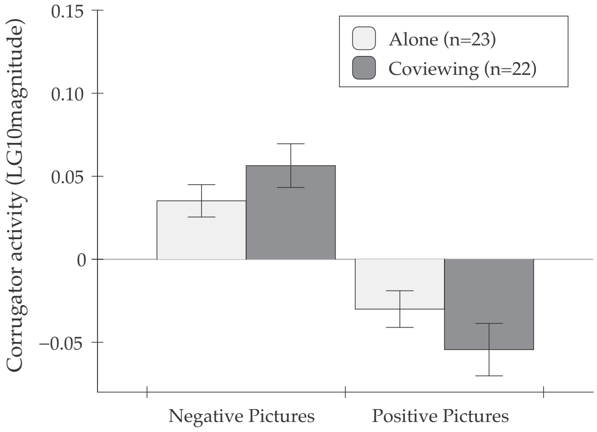

Fig. 3. Mean corrugator EMG activity as a function of Agent Presence and Valence of stimuli. Error bars represent 1 SEM.

smiling activity to positive stimuli was enhanced by the presence of an agent in the virtual environment. Although participants did not interact with the agents, their digitized human form was enough to potentiate smiling expressions in a manner consistent with previous laboratory-based studies using human co-viewers (e.g., Fridlund, 1991; Hess et al., 1995). This study therefore provides yet another critical replication using IVE of real-world studies of social influence, and it provides support for the notion that the sociality effect is indeed ubiquitous.

As a consequence of examining the influence of stimulus valence and agent presence on facial expressions, our design also permitted us to examine what effect, if any, social cues had on responses to negative stimuli and corrugator activity. The agent presence manipulation had no effect on the pleasantness ratings. However, a marginally significant pattern of results emerged for the corrugator region, indicating that social cues may potentiate corrugator activity to negative stimuli and inhibit it to positive stimuli. Because previous studies of the sociality effect measured corrugator activity only as a means to control for general muscle activity (Fridlund, 1991) or concomitant negative affect (Hess et al., 1995), it is difficult to know whether our corrugator findings are indicative of an under-powered social presence effect or represent a null effect. Although the direction of the interaction suggests that sociality might intensify corrugator activity to unpleasant stimuli and reduce activity to pleasant stimuli, further research will be needed to adequately test for a sociality effect when viewing negative stimuli.

Taken as a whole, these results suggest that the perceived presence of co-actors leads to less inhibited expressions of experienced affect. Co-viewing may not influence zygomaticus activity in response to negative stimuli simply because activation of the zygomaticus muscle has a quadratic, non-linear association with affective stimuli (especially pictures; Larsen et al., 2003) – increasing in response to increasingly pleasant stimuli and remaining unchanged in response to increasingly unpleasant stimuli. For this reason, the expression-potentiation brought on by co-viewing should be relevant only for stimuli that the zygomaticus is sensitive to in the first place.

This study also highlights the usefulness of facial EMG in this context, as methods of visual facial coding are difficult when a HMD is in place. Despite the potential interference of the head-mounted display on the physiological signals and the lack of social interaction with the agents, this study clearly demonstrates that feasibility of measuring the influence of both affective and social cues in a virtual environment using facial EMG.

A limitation of this study is that we did not measure presence or immersion – "the subjective experience of being in one place or environment" (Witmer and Singer, 1998, p. 225). Thus, we are unable to report how the participants perceived the agents. However, because all participants were subjected to the same IVET paradigm, and based on participants' spontaneous comments during the debriefing, we believe that the overall degree of immersion was both high and comparable across participants (Baños et al., 2004). Indeed, adaptions of this paradigm in future research could be made so that the agents are rendered to show greater behavioral realism (e.g., walking into the room and taking a seat) or to elicit more self-relevance (e.g., through prior interaction on a task). Our results indicate that such manipulations would increase the sociality effect.

In sum, this study demonstrates that spontaneous facial expressions may be a particularly fruitful response measure in virtual environments when behavioral realism, social presence, and/or self-relevance is low. Virtual environments are increasingly used by a variety of disciplines both as a method of understanding social phenomena and as a tool for teaching real-world behaviors in a controlled environment (Fox et al., 2009). As such, it is increasingly important to understand the factors that influence social behaviors and perceptions in IVEs. This study provides further support for the notion that even the most nominal of social cues may affect automatic social responses in virtual environments (McCall and Blascovich, 2009).

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