Virtual friend or threat? The effects of facial expression and gaze interaction on psychophysiological responses and emotional experience

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Abstract

The present study aimed to investigate the impact of facial expression, gaze interaction, and gender on attention allocation, physiological arousal, facial muscle responses, and emotional experience in simulated social interactions. Participants viewed animated virtual characters varying in terms of gender, gaze interaction, and facial expression. We recorded facial EMG, fixation duration, pupil size, and subjective experience. Subject's rapid facial reactions (RFRs) differentiated more clearly between the character's happy and angry expression in the condition of mutual eye-to-eye contact. This finding provides evidence for the idea that RFRs are not simply motor responses, but part of an emotional reaction. Eye movement data showed that fixations were longer in response to both angry and neutral faces than to happy faces, thereby suggesting that attention is preferentially allocated to cues indicating potential threat during social interaction.

Descriptors: EMG, Eye movements, Facial expression, Mutual gaze, Nonverbal communication, Pupillometry, Virtual characters

In recent years, virtual reality (VR) methods have been established as useful in the study of nonverbal communication. They allow for both realistic stimuli and high experimental control (Kätsyri, Klucharev, Frydrych, & Sams, 2003). Virtual characters are able to evoke a sense of social presence (Bailenson, Blascovich, Beall, & Loomis, 2003), and transmit facial expressions as adequate and intensive as photographs of human actors depicting the same expressions (Spencer-Smith et al., 2001; Wehrle, Kaiser, Schmidt, & Scherer, 2000).

Also, virtual characters have been shown to evoke differential facial muscle activity when depicting positive and negative facial expressions (Mühlberger, Kund, Pauli, & Weyers, 2006; Mojzisch et al., 2006; Weyers, Mühlberger, Hefele, & Pauli, 2006). The phenomenon that observers tend to spontaneously produce facial movements similar to the facial expression of the person observed has been supported by a substantial number of electromyographic (EMG) studies (e.g., Blairy, Herrera, & Hess, 1999; Dimberg & Lundquist, 1990; Dimberg & Thunberg, 1998). Such studies typically record muscular reactions of the zygomaticus major, which pulls the corners of the mouth up and back, and the corrugator supercilii, which pull the eyebrows together and downwards. Generally, corrugator supercilii activity is higher in response to frowning faces, whereas zygomaticus major activity is higher in response to smiling faces. These rapid facial reactions (RFRs, Moody, McIntosh, Mann, & Weisser, 2007) can be observed as soon as 300 ms after stimulus presentation (Dimberg & Thunberg, 1998), with strong effects between 500 and 1000 ms (e.g., Moody et al., 2007; Mühlberger et al., 2006; Weyers et al., 2006). Since they even occur if stimuli are presented subliminally (Dimberg, Thunberg, & Elmehed, 2000) and cannot be avoided voluntarily (Dimberg, Thunberg, & Grunedal, 2002), it was suggested that RFRs are automatic processes (Dimberg et al., 2002). Although RFRs have been related to the human mirror neuron system (e.g., Ferrari, Gallese, Rizzolatti, & Fogassi, 2003; Parr, Waller, & Fugate, 2005), an interpretation as simple mimicking behavior cannot explain why RFRs can be observed following exposure to emotive pictures (e.g., Hamm, Cuthbert, Gallese, & Rizzolatti, 2003) or during happy or sad mood induction (Schwartz, Fair, Salt, Mandel, & Klerman, 1976). These findings suggest RFRs as being part of an affective response. As proposed by Hess, Philippot, and Blairy (1998), observing another person’s facial...
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EMG activity from the interactions by recording pupil size, fixation duration, and interaction. The dorsal part was differentially activated depending on mutual gaze cognition. Whereas the ventral part of mPFC was recruited during biting. The resulting four conditions thus established a 2 (gaze socially relevant (e.g., winking, smiling) or arbitrary (e.g., lip-turning) turned either directly towards the observer (resulting in mutual eye-to-eye contact) or towards an imaginary third person. Direct body orientation of the virtual character was intended to create a feeling of personal involvement, whereas averted body orientation turned the subject into a passive observer of the interaction. The character then displayed a facial expression which could be socially relevant (e.g., winking, smiling) or arbitrary (e.g., lip-biting). The resulting four conditions thus established a 2 (gaze interaction: yes vs. no) × 2 (social relevance of facial expression: yes vs. no) factorial design. Results indicated a role of medial prefrontal cortex (mPFC) in emotional processing and social cognition. Whereas the ventral part of mPFC was recruited during the analysis of the social meaning of the facial expression, the dorsal part was differentially activated depending on mutual gaze interaction.

Mojzisch et al. (2006) applied Schilbach et al.’s (2006) paradigm to address psychophysiological aspects of social interactions by recording pupil size, fixation duration, and EMG activity from the *zygomaticus major* muscle. It was found that more visual attention, indicated by increased fixation duration, was allocated to characters that turned directly towards the observer. Physiological arousal, measured by pupil size, increased in response to female compared to male characters. *Zygomaticus major* activity was increased if the virtual characters displayed socially relevant facial expressions (compared to arbitrary facial movements). This effect occurred even if participants were not personally addressed by the virtual characters.

For the present study, Schilbach et al.’s (2006) paradigm was modified to address some methodological limitations. Firstly, most of the socially relevant facial movements in the previous two studies (Mojzisch et al., 2006; Schilbach et al., 2006) were rather positive social signals (e.g., winking, smiling) and hence might have provoked positive emotional reactions instead of social meaning in general. We therefore aimed to disentangle the social meaning of facial expression and its valence by using happy, angry, and neutral expressions to indicate potentially pleasant, unpleasant, or neutral interactions. We expected this differentiation to lead to differences in visual attention and facial EMG. As visual attention seems to be particularly allocated to faces expressing threat (Fox & Damjanovic, 2006; Green, Williams, & Davidson, 2003; Lundqvist & Öhman, 2005), the facial expression’s valence might influence fixation duration. EMG activity was recorded from the *zygomaticus major* and *corrugator supercilii* in order to find differential results depending on the character’s expression.

A second limitation of the two previous studies (Schilbach et al., 2006; Mojzisch et al., 2006) was that only male subjects participated. Therefore, it remained unclear if gender effects on pupil size and fixation duration resulted from an interaction between the virtual character’s and the subject’s gender or reflected a main effect of the characters’ gender. In particular, the observation of larger pupil sizes for female virtual characters in the Mojzisch et al. study could be due to female characters having a higher evolutionary significance for the male subjects (interaction effect) or due to female characters being more salient in general (main effect). Examining male and female subjects should clarify this issue.

Moreover, we extended the previous studies (Mojzisch et al., 2006; Schilbach et al., 2006) by examining whether virtual characters’ facial expression could induce a corresponding emotional experience. This enabled us to differentiate whether expected RFRs were merely mimicking behavior or rather affective responses.

To summarize, interactive effects of facial expression and mutual gaze on visual attention, facial EMG, and emotional experience have hardly been examined. The aim of the present study was to investigate the interactive effects of dynamic facial expressions and gaze interaction during short social interactions with male and female virtual characters. Specifically, we focused on the effects of facial expression and gaze interaction on (1) visual attention as measured by fixation duration, (2) physiological arousal as indicated by pupil size, (3) facial EMG, and (4) emotional experience.

Method

Participants

Forty-four subjects (22 females) with a mean age of 23.09 years (*SD* = 3.11) were recruited at the Technische Universität Dresden. Subjects gave informed consent for their participation and were kept naïve in terms of the study’s purpose. All participants had normal or corrected-to-normal vision and received either course credit or €5 per hour in compensation.

Design

The present study investigated four independent variables including the virtual character’s gender (female vs. male), gaze interaction (me vs. other) and facial expression (angry vs. happy vs. neutral) as within-subjects factors and the observer’s gender (female vs. male) as between-subjects factor resulting in a 2 × 2 × 3 × 2 mixed factorial design. We relabeled the variable ‘self-involvement’ from the previous studies (Mojzisch et al., 2006; Schilbach et al., 2006) as gaze interaction. This term emphasizes the idea that the character either turned to the subject, resulting in mutual gaze, or turned to an imaginary person with no eye contact. Note that we thus did not manipulate gaze direction *per se* but body orientation.

Dependent Variables

Eye Movement Data

Fixation duration and pupil size were recorded with a head-mounted EyeLink I Eyetracking System (SR Research, Osgoode, ON, Canada) with a sample rate of 250 Hz and a spatial resolution of 0.5–1°. The position of the eye was detected using...
bright pupil image. Pupil size was measured in arbitrary integer units referring to pupil diameter.

**Facial EMG**

Facial EMG was measured bipolarly over the regions of the *M. zygomaticus major* and the *M. corrugator supercilii* on the right side of the face according to the guidelines of Fridlund and Cacioppo (1986). A reference electrode was attached to the right earlobe and a ground electrode was attached to the left earlobe. We used Ag-AgCl miniature surface electrodes filled with electrode paste. Before attachment, the skin was cleaned with electrode paste and alcohol. EMG activity was recorded using a BrainAmp amplifier (Brain Products GmbH, Munich, Germany), digitized at 1000 Hz and stored on a laboratory computer.

**Subjective Ratings**

After every video sequence, subjects rated their emotional experience during the perception of the character’s facial expression on the Self-Assessment-Manikin (SAM; Lang, 1980), a non-verbal self-report measure. It consists of three bipolar nine-point scales representing the affective dimensions valence, arousal and dominance.

**Stimuli**

Stimulus material consisted of video sequences depicting virtual characters moving across the screen. Each video sequence adhered to a standardized temporal sequence of 7.5 s: Firstly, the character entered the screen from the left or from the right (walk in: 0–1500 ms). Due to different sizes of male and female characters, they were completely visible in 133 to 300 ms, respectively. Characters then either turned towards the observer resulting in mutual eye-to-eye contact or turned towards an imaginary third person located 30° to the left or to the right of the observer (turn: 1500–2500 ms).

In the next video segment, the character displayed either a happy, angry, or neutral facial expression (emotion: 2500–5500 ms). The facial expression increased from 2900 ms to the apex at 3300 ms and then decreased from 3800 to 4900 ms. A residual expression of half of the apex’ intensity was then maintained for the rest of the clip. Finally, the character turned away and walked out of the screen frame (turn and walk out: 5500–7500 ms). Figure 1 shows screenshots of all twelve possible combinations of the three within-subjects factors.

Virtual characters (6 male, 6 female) were presented in front of a gray background. Only their heads and shoulders were visible. Illumination, camera settings, and viewing distance were kept constant. To give the characters a more natural appearance, they displayed a standardized pattern of small jerky horizontal eye movements, which simulated saccades. In one fifth of randomly selected video clips, they made a blink between 4700 and 4900 ms. Hair color (light or dark) and direction of the character’s entrance (from the left or from the right) were counterbalanced. The video clips were created using the software package “Poser 6” (Curious Lab, Santa Cruz, CA). The different facial expressions were obtained by manipulating polygon groups on a 3D-mesh which makes up the character’s facial structure. The polygon groups were comparable to the Action Units as described in the Facial Action Coding System (FACS; Ekman & Friesen, 1978). For female and male virtual characters, one expression of happiness and anger was created. FACS codes for the anger expression were 2b+4b/c+9b/11A+24C for male and 2a+4c+9a/b+24b/c for female characters. FACS codes for happiness were 6b+12c and 6b/c+12c, respectively. Animation of facial and body motion was realized by interpolating images between different facial configurations and body positions. The single pictures of a scene were rendered with Poser 6 and compiled to videos with MATLAB (MathWorks, Natick, MA) using the INDEO 5.1 Codec (for illustration, examples of the video clips are demonstrated at http://ircwww.urz.tu-dresden.de/~cogsci/examples.html).

Stimuli were presented using a Radeon 9200 graphic card and a CRT display (19-inch Iiyama Vision Master 452) with a resolution of 1024×768 pixels and a frame rate of 100 Hz. Viewed from a distance of 80 cm, the resulting visual angle was 27° horizontally and 19° vertically.

**Behavioral Pilot Studies**

Two pilot studies were conducted. In the first study (N = 62, 36 women), appearance and attributes of 24 virtual characters were assessed. Only those of European descent, classified into the intended age category (25–35 years), rated as being distinctly male or female, having medium levels of attractiveness and sympathy and high levels of naturalness were selected for the subsequent experiment. To account for the comparability of the retained six male and six female virtual characters, differences between them were tested with the Mann-Whitney U test. As expected, male characters were rated significantly higher on the female-male scale (Mdn = 7.00; Inter-quartile range [IQR] 6.75–7.00) than female characters (Mdn = 1.50; IQR 1.00–2.00). Mann-Whitney U test, z = −3.035, p < .01. Male characters tended to be rated higher on the dominance, sociability, and naturalness scale by at most one scale point. However, these differences were not significant.

The second pilot study (N = 52, 37 women) aimed to validate the character’s facial expressions of happiness and anger. Subjects rated the valence, naturalness, and intensity of the expressions on bipolar scales ranging from 1 (negative, artificial, weak) to 7 (positive, natural, strong). Valence ratings were relatively high for happiness for both male and female characters (Mdn ≥ 5.25; IQRs 5.00–6.00) and they were low for anger (Mdn ≤ 2.00; IQRs 2.00–2.00). This corresponded to the intended expression valence. Intensity was rated identically for “happy” male (Mdn = 5.00; IQR 5.00–5.00) and female characters (Mdn = 5.00; IQR 4.74–5.00) as well as “angry” male (Mdn = 5.00; IQR 5.00–6.00) and female characters (Mdn = 5.00; IQR 5.00–5.00). Naturalness was rated at the same level with the exception of “happy” female characters (Mdn = 3.25; IQR 3.00–4.00). Subjects further rated the expressions on unipolar scales of the six basic emotions (anger, sadness, fear, happiness, disgust, and surprise) ranging from 0 (does not apply at all) to 4 (applies totally). The expressions were unambiguously identified. Specifically, anger was rated high on the anger scale for male (Mdn = 3.00; IQR 2.75–3.00) and female (Mdn = 3.00; IQR 3.00–3.00) characters. In contrast, happiness was rated high on the happiness scale for male (Mdn = 3.00; IQR 3.00–3.00) and female characters (Mdn = 3.00; IQR 2.88–3.00). Both expressions were rated low on all non-relevant emotions (Mdn ≤ 1.00). Mann-Whitney U test yielded no significant differences between male and female characters.

**Procedure**

Subjects were tested individually in a sound-attenuated, light-dimmed laboratory room. They viewed standard instructions on
the computer screen. The experiment was preceded by five training trials. In total, participants watched 120 video clips with 10 clips for each combination of within-subjects factors (character’s gender × gaze interaction × facial expression). After each clip, four items were displayed. First, subjects were asked to indicate whether the character had looked at them or at one of the other two observers by answering the question “Me?” with “yes” or “no.” This question was included to ensure that subjects kept on attending the character’s body orientation during each clip. Then, the three SAM-scales were presented, varying randomly in terms of their order.

The video clips were grouped into five blocks which were counterbalanced for the manipulated and control variables. The blocks as well as the video clips within the blocks were presented randomly. After each block, participants had the possibility to take a break.

Eye movements and facial EMG were recorded throughout the experiment. A 9-point calibration and validation routine of the eye tracker was performed before each block. Each trial followed a drift correction procedure. To keep participants naïve regarding the purpose of the EMG, they were told that the EMG electrodes served the recording of head movements and shifts of the head-mounted system to correct the eye tracking data later on.

Data Analysis
Eye tracking data from two subjects were discarded as one subject reported a neurological disorder and the other wrongly indicated the character’s body orientation in 43% of the trials. Error rate for the remaining subjects was at the most 4%. Due to technical problems, four subjects were additionally discarded from analysis of EMG data. EMG signals were highpass filtered at 20 Hz and rectified. To prevent the results from being distorted by voluntary muscle movements, standard deviations for each subject and each condition were calculated, and data points beyond the span of two standard deviations were excluded from the analysis. A baseline was recorded during a 300 ms interval before each video clip. Final EMG activity was calculated by subtracting the baseline from the raw score and dividing it by 1000. The raw score represented the average activity of all data points within this interval.

In the eye movement data, fixations followed by a blink, prior to the entrance of the character, shorter than 100 ms or outside the presentation screen were excluded. Following the rationale of Mojzisch et al. (2006), video clips were segmented into three intervals. The segments were thought to differ in terms of the manipulated variables that were actually operating. Specifically, in the walk in segment, only the virtual character’s gender was observable and thus able to induce an effect. The turn segment then revealed if the subject would be personally addressed by the virtual character or not. Hence, in this video segment gaze interaction could operate as a second within-subjects factor. Finally, in the emotion segment, the character displayed the facial expression, so that variations of all three within-subjects factors were now observable. As visual perception is impaired for at least 50 ms before and after the start of a saccade (Diamond, Ross, & Morrone, 2000), fixations were categorized into a segment if they had started not earlier than 50 ms before and not later than 50 ms after the time segment. As fixations shorter than 100 ms were excluded from the analysis, no fixation could have been classified into two segments at the same time.

Results
Fixation Duration
Medians of the eye-tracking data were calculated for each subject, time segment, and condition. These were submitted to a five-way repeated measures analysis of variance (ANOVA) with video segment (walk in, turn, emotion), character’s gender (male, female), gaze interaction (me, other), and facial expression (angry, happy, neutral) as within-subjects factors and the subject’s gender (male, female) as between-subjects factor.\(^1\) We did neither expect an effect of gaze interaction during the walk in segment nor an effect of facial expression during the walk in or turn segment. Analyzing all time segments at the same time allowed us to show that the resulting effects were solely caused by the manipulated variables. If necessary, Greenhouse-Geisser correction was applied to account for violations of the sphericity assump-

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Footnote:
\(^1\) For exploratory reasons, we also tested whether the direction which the virtual characters turned (i.e., to the left or to the right) had any effect. Results revealed no significant effect of turning direction for the main dependent variables. Therefore, this variable was not included as a factor in the subsequent analyses.
As outlined above, we measured fixation duration as an index of attention allocation. Data analysis revealed a significant effect of time segment, $F(2,80) = 35.342$, $p < .001$, $\eta_p^2 = .469$, consisting of an increasing fixation duration from the walk in to the emotion segment. Post hoc comparisons indicated significant differences between all segments, all $p$s $\leq .001$. Furthermore, results showed a significant effect of the character’s facial expression, $F(2,80) = 3.852$, $p < .05$, $\eta_p^2 = .088$ with shorter fixations on happy as compared to angry and neutral faces, both $p$s $< .05$. No differences were found between the angry and the neutral faces, $p = .882$. Significant interactions were obtained between time segment and each of the manipulated variables (see Table 1). First, results yielded a significant interaction between time segment and gender of the virtual character, $F(2,39) = 5.093$, $p < .01$, $\eta_p^2 = .225$. Simple effect analyses revealed that, in the walk in segment, fixations were longer for male than for female characters, $F(1,40) = 21.398$, $p < .001$, $\eta_p^2 = .349$. In contrast, there were no differences in the turn, $F < 1$, and the emotion segment, $F(1,40) = 2.239$, $p = .142$. Second, there was a significant interaction between time segment and gaze interaction, $F(2,80) = 7.206$, $p < .001$, $\eta_p^2 = .153$. During the turn segment, longer fixations were found if the character looked directly at the subject than if the character looked at somebody else, $F(1,40) = 17.201$, $p < .001$, $\eta_p^2 = .301$. No differences were obtained in the walk in, $F(1,40) = 1.646$, $p = .207$, and the emotion segment, $F < 1$. Thirdly, the interaction between time segment and facial expression was significant, $F(4,160) = 6.059$, $p < .001$, $\eta_p^2 = .132$. Simple effect analyses revealed that, only in the emotion segment, facial expression had a significant effect on fixation duration, $F(2,39) = 7.786$, $p = .001$, $\eta_p^2 = .285$. Post hoc tests yielded shorter fixations for happy compared to angry and neutral facial expressions, both $p$s $< .05$, with no significant difference between angry and neutral faces, $p = .463$. No effects were found for the walk in, $F(2,39) = 2.525$, $p = .093$, and the turn segment, $F < 1$.

Apart from these three distinctive effects, there was a significant interaction between the character’s gender and gaze interaction, $F(1,40) = 11.567$, $p < .01$, $\eta_p^2 = .224$. Simple effect analysis showed an effect of the character’s gender only if the virtual character was averted, with longer fixations to male characters, $F(1,40) = 10.354$, $p < .01$, $\eta_p^2 = .206$. There was no effect of the character’s gender in the mutual gaze condition, $F(1,40) = 1.994$, $p = .166$. Furthermore, simple effects of gaze interaction were only significant for female characters, reflecting that fixations were longer for the directly turned than for the averted character, $F(1,40) = 6.864$, $p < .05$, $\eta_p^2 = .146$. No interaction between the character’s and the observer’s gender was found, $F(1,40) = 1.251$, $p = .270$.

### Table 1. Effects of the Character's Gender, Gaze Interaction, and Facial Expression on Fixation Duration

<table>
<thead>
<tr>
<th>Character’s gender</th>
<th>Gaze interaction</th>
<th>Facial expression</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Female</td>
<td>Male</td>
</tr>
<tr>
<td>Walk in</td>
<td>277.46 (6.93)</td>
<td>306.20*** (10.09)</td>
</tr>
<tr>
<td>Turn</td>
<td>329.73 (10.69)</td>
<td>327.14 (9.44)</td>
</tr>
<tr>
<td>Emotion</td>
<td>400.49 (15.08)</td>
<td>388.53 (14.17)</td>
</tr>
</tbody>
</table>

*Note: Cells contain mean values of fixation duration in milliseconds. Standard errors are given in parentheses. Asterisks indicate results of simple effect analyses.*** $p \leq .001$.

### Pupil Size

Pupil size was measured as an index of stimulus-induced arousal (Bradley, Miccoli, Escrig, & Lang, 2008). To control for an influence of luminance on pupil size, the five-way repeated measures ANOVA was extended by luminance as a covariate. Mean luminance of each video clip’s time segments and the mean luminance of each clip were calculated. We analyzed median residuals of a regression analysis with luminance values as predictor and pupil size as criterion. Analysis revealed an effect of time segment, $F(2,80) = 195.416$, $p < .001$, $\varepsilon = .644$, $\eta_p^2 = .830$, that is, an increase in pupil size from the walk in to the emotion segment. All differences between the time segments were significant (all $p$s $< .001$). Furthermore, there was a significant effect of the character’s gender, $F(1,40) = 5.109$, $p < .01$, $\eta_p^2 = .192$. Pupil sizes were larger in response to female than to male characters irrespective of the subject’s gender, $F < 1$. All other effects were non-significant.

### EMG

Rapid facial reactions have been shown to occur as soon as 300 to 500 ms after stimulus presentation (Dimberg, 1997; Dimberg & Thunberg, 1998), with the strongest effects to be expected between 500 and 1000 ms (Moody et al., 2007; Mühlberger et al., 2006; Weyers et al., 2006). We therefore calculated median EMG activity during the 500 to 1000 ms interval following the apex of the character’s facial expression (at 3300 ms). Data were submitted to a four-way repeated measures ANOVA with the virtual character’s gender, gaze interaction, and facial expression as within-subjects factors and the subject’s gender as between-subjects factor. Greenhouse-Geisser correction was applied if necessary.

As expected, analysis of zygomaticus major activity revealed a significant effect of facial expression, $F(2,72) = 8.876$, $p < .01$, $\eta_p^2 = .132$. Post hoc tests yielded higher muscle activity for happy than for neutral expressions, $p < .01$, but no difference between happy and angry, $p = .475$, as well as angry and neutral expressions, $p = .270$. This main effect can be clarified by a two-way interaction between facial expression and gaze interaction, $F(2,72) = 11.938$, $p < .001$, $\eta_p^2 = .249$, indicating that facial expression only had an effect if the character directly turned towards the observer, $F(2,35) = 6.659$, $p < .01$, $\eta_p^2 = .276$. Zygomaticus major activity was significantly higher for happy
than for neutral and angry expressions, both ps < .01, but did not differ between angry and neutral expressions, p = 1.00. There was no effect of facial expression if the character turned to somebody else, F(2,35) = 2.228, p = .123.

Consistently, analysis of corrugator supercilii activity also revealed a significant effect of facial expression, F(2,72) = 6.384, p < .01, η² = .151, which again could be qualified by a two-way interaction of gaze interaction and facial expression, F(2,72) = 4.082, p < .05, η² = .102. Analyses of simple effects showed that for the mutual gaze condition, F(2,35) = 9.904, p < .001, η² = .361, corrugator supercilii activity was higher for angry and neutral compared to the happy expression, both ps < .05 in the post hoc tests, with no difference between the angry and the neutral expression, p = 1.00. However, if the character turned to somebody else, F(2,35) = 11.132, p < .001, η² = .389, only the difference between happy and neutral expressions was significant, p < .001, but not between the other expressions, p ≥ .283. Interaction effects on both facial muscles are depicted in Figure 2.

We also found a significant interaction between the subject’s and the character’s gender on zygomaticus major activity, F(1,36) = 4.333, p < .05, η² = .107, showing stronger responses to male than to female characters only for female, F(1,36) = 5.548, p < .05, η² = .134, but not for male subjects, F < 1. For the corrugator supercilii, analyses also yielded an interaction effect involving the character’s and the subject’s gender, and the character’s facial expression, F(2,72) = 3.614, p < .05, η² = .091. Due to the complexity of this interaction, results of simple effect analyses are not reported here.

**Subjective Experience**

To analyze the SAM rankings, valence was coded from −4 (low) to +4 (high), and arousal and dominance from 1 (low) to 9 (high). Medians were calculated for each subject and condition. Data were submitted to a four-way ANOVA of the experimental design.

For valence, there was a significant effect of facial expression, F(2,80) = 187.328, p < .001, η² = .824. Valence ratings were highest for happy faces (M = 1.95; SE = 0.14), followed by neutral faces (M = 0.08; SE = 0.05) and lowest for angry faces (M = −1.67; SE = 0.16), with all post hoc comparisons being significant at p < .001. A significant interaction was found between gaze interaction and facial expression, F(2,80) = 53.289, p < .001, η² = .571. When characters displayed an angry expression, valence was ranked higher for averted (M = −1.35; SE = 0.16) than for directly turned characters (M = −1.99; SE = 0.16), F(0,11) = 60.124, p < .001, η² = .600. By contrast, when the character showed a happy expression, valence was ranked higher for directly turned (M = 2.36; SE = 0.14) than for averted characters (M = 1.55; SE = 0.17), F(0,11) = 39.862, p < .001, η² = .499. Note that these interaction effects can also be interpreted as a main effect: For both happy and angry expression, emotional experience was more pronounced if the virtual character turned to the subjects, resulting in mutual eye-to-eye contact.

Analyses of the arousal ratings yielded a significant effect of gaze interaction, F(1,40) = 53.367, p < .001, η² = .572. Arousal was higher for directly turned characters (M = 4.13; SE = 0.18) than for averted characters (M = 3.65; SE = 0.17). Arousal also differed significantly depending on the virtual character’s facial expression, F(2,80) = 60.179, p < .001, η² = .601. It was ranked higher for angry (M = 5.14; SE = 0.26) than for happy (M = 3.42; SE = 0.21) and neutral facial expressions (M = 3.11; SE = 0.16), both at ps < .001. Happy and neutral expressions did not differ significantly from each other, p = .353.

Concerning dominance, results revealed a significant interaction between gaze interaction and facial expression, F(2,80) = 11.595, p < .001, η² = .225. If the character displayed an angry expression, dominance was rated higher for the averted (M = 5.26; SE = 0.19) than for the mutual gaze condition (M = 4.92; SE = 0.23), F(1,40) = 4.127, p < .05, η² = .094. Conversely, if the character displayed happiness, dominance was rated higher for directly turned (M = 5.52; SE = 0.25) than for averted characters, (M = 5.14; SE = 0.23), F(1,40) = 10.029, p < .01, η² = .200.

**Discussion**

The present study applied a VR paradigm, allowing a realistic and dynamic but still controlled setting. We aimed to supplement findings of a recent psychophysiological study (Mojzisch et al., 2006) by investigating the interactive effects of facial expression, gaze interaction, and gender information on visual attention, physiological arousal, FRFRs, and emotional experience during positive, negative, and neutral social interactions with virtual others.

**Visual Attention**

Visual attention, as indicated by fixation duration, was immediately influenced by the character’s gender, by gaze interaction between the character and the observer, and by the character’s facial expression. When the character entered the scene, fixations were longer for male than for female characters regardless of the subject’s gender. This result is directly opposed to Mojzisch et al.’s (2006) findings, namely prolonged fixations for female characters. Notably, in our pilot studies, male characters were ranked somewhat higher than female characters on naturalness, dominance, and sociability (albeit non-significantly). It could be assumed that male interaction partners attract more attention due to perceived higher social power, status, and dominance (Hess, Adams, & Kleck, 2005; LaFrance & Hecht, 2000). Interestingly, we found no effect of the character’s gender in the mutual gaze condition but only if the character turned to someone else. However, the reliability of this finding needs to be further demonstrated, so these interpretations remain tentative.
During the turn segment, fixation duration was influenced by gaze interaction. As in the previous study (Mojzisch et al., 2006), subjects produced longer fixations if they were directly gazed at by the character than if they were passive observers of interacting others. This result is in line with Argyle and Cook’s (1976) suggestion that mutual gaze “seems to have a special significance and is sometimes experienced as a special kind of intimacy, mutual access, and meeting of minds” (p. 170; see also Baron-Cohen, 1995). In line with this idea, studies presenting faces looking either towards or away from the target found evidence of a reflexive gaze cue effect (Driver et al., 1999; Friessen & Kingstone, 1998; Friessen, Moore, & Kingstone, 2005). By addressing longer fixations to faces with direct gaze, an interaction partner may benefit from socially relevant information conveyed by the microbehavior of a partner’s eyes. A lack of this ability in patients with autism (e.g., Dalton et al., 2005; Neumann, Spezio, Piven, & Adolphs, 2006; Pelphrey et al., 2002) might contribute to their difficulties in attributing mental states to others (e.g., Baron-Cohen, Wheelwright, & Jolliffe, 1997). Allocating visual attention to mutual gaze therefore seems to build a basis for higher social cognitive skills like joint attention and Theory of Mind (Baron-Cohen, 1995; Tomasello & Carpenter, 2007; Tomasello, Carpenter, Call, Behne, & Moll, 2005; Velichkovsky, 1995).

Finally, during the emotion segment, fixation duration was longer for the angry and neutral expression than for the happy one. Similar results were reported by Green et al. (2003), who found longer fixations on threat-related expressions, including anger, compared to threat-irrelevant expressions. Also, visual search studies have found that angry faces are typically detected more quickly and accurately than happy ones (Fox & Damjanovic, 2006; Lundqvist & Ohman, 2005; Ohman, Lundqvist, & Esteves, 2001). Thus, attention allocation during interaction may reflect the need to prepare an adaptive response to social threat.

Remarkably, our results revealed that fixation duration was not only prolonged towards angry, but also towards neutral faces. This could reflect that subjects were waiting for a movement in the face. Also, a face that does not transmit any information might be perceived as threatening. In other words, “a truly neutral face, lacking any invitation to interact, is easily interpreted as slightly hostile” (Öhman et al., 2001, p. 382). Only the happy expression would signal safety and would therefore be the least interesting one, as indicated by shorter fixations.

To the best of our knowledge, our results are the first demonstration of this effect using dynamic animations of facial expressions.

Physiological Arousal

In line with Mojzisch et al.’s (2006) results, the character’s gender had a significant effect on pupil size in all time segments. Pupil sizes were larger in response to female than to male characters. As this effect emerged both for male and female subjects, explanations in terms of mate-search motives seem to be outdated. We rather suggest that different expectations towards a male or female interaction partner might account for this effect. For instance, it is a well-founded result that women smile more frequently than do men (Hall & Halberstadt, 1986; LaFrance & Hecht, 2000). This effect has been attributed to gender-specific norms, indicating that women express emotions more strongly, smile more, and are more socially oriented than men (Eagly, 1987; LaFrance & Hecht, 2000). Therefore, higher arousal in response to female characters might reflect the subject’s expectation of an affiliative, and thus potentially more rewarding, interaction from a female than a male interaction partner. Yet, explanations of the effect of gender on pupil size and fixation duration remain speculative.

Notably, an important finding that goes beyond the previous study (Mojzisch et al., 2006) is that results of both eye parameters suggest the absence of interaction effects between the virtual character’s and the observer’s gender. Instead, reactions seem to reflect a general appraisal of a social counterpart in terms of potential threat or reward from an interaction.

Moreover, the fact that pupil size was not affected by gaze interaction suggests that pupillary response (with its excessive latency, see Janisse, 1977) is more sensitive to invariant facial features like gender than to rapidly changeable characteristics like body orientation.

Facial Expression

Previous EMG studies have consistently demonstrated that individuals tend to react with congruent facial muscle activity when looking at emotional faces. In the present study, we examined whether these RFRs are moderated by gaze interaction and by gender information.

Replicating earlier research, our results revealed that subjects showed congruent RFRs in response to the virtual character’s emotional expressions. Specifically, zygomaticus major activity was higher for the happy than for the angry expression and corrugator supercilii activity was higher for the angry than for the happy expression. Importantly, we also found that RFRs differentiated more clearly between happy and angry expressions when virtual characters turned towards the subjects compared to when the character was looking at someone else. These results are the first to show that RFRs are influenced by gaze interaction. Note that this finding is somewhat in contrast with Mojzisch et al. (2006), who found higher corrugator major activity to smiling characters for both the directly turned and the averted character. However, even in this study muscle activity was slightly higher (albeit not significantly) if the subjects were looked at directly. In fact, the finding that RFRs may be affected by different conditions of eye contact is in line with recent studies showing that RFRs are not purely reflexive but can be moderated by several variables. In particular, there is evidence that RFRs are influenced by attitude towards an interaction partner (Likowski, Mühlberger, Seibt, Pauli, & Weyers, 2008; McIntosh, 2006), by cues relevant to the shared group status of observer and target (Bourgeois & Hess, 2008), and by the person’s emotional state (Moody et al., 2007). Our finding hence supports the view that RFRs are not simply motor responses, but part of an emotional response. Alternatively, it might be argued that if the character turned to the side, subjects did not receive as much information about the facial expression as in the mutual gaze condition. However, this alternative explanation is not in line with results of fixation duration, revealing an effect of the character’s facial expression independent of gaze interaction.

Interestingly, response of the corrugator supercilii was not only higher to angry but also to neutral facial expressions when compared to happy expressions. This may be explained by an obvious relaxation of the corrugator supercilii to happy expressions. Such an effect has also been reported in previous EMG studies (e.g., Achaibou, Pourtois, Schwartz, & Vuilleumier, 2008; Dimberg & Thunberg, 1998; Dimberg et al., 2002) and has been interpreted as resulting from natural frowning activity during baseline (Achaibou et al., 2008) that is maintained towards neutral expressions and released towards happy expressions.
It has to be considered that differential activity of the corrugator supercili muscle also emerged (although less intensive) if the characters gazed at someone else. An explanation could be that the zygomaticus major is more easily accessible to voluntary control than the corrugator supercili—a characteristic which probably results from the zygomaticus major’s better representation in the motor cortex and its greater contralateral innervation (Larsen et al., 2003). Tentative support for this idea comes from a post hoc analysis of our data, contrasting two groups—subjects who remained naïve in terms of the EMG and those who came up with adequate ideas.² Though basic results in both groups were approximately the same, suspicion about the investigation of facial expression lead to stronger results in both groups were approximately the same, suspicion about the EMG electrode’s true purpose.

The present experiment investigated effects of social interaction with virtual characters on measures of visual attention, physiological arousal, RFRs, and emotional experience. Visual attention was especially allocated to mutual eye-to-eye contact as well as to neutral and angry facial expressions, thereby providing evidence for mechanisms drawing attention to potential social threat. Physiological arousal was influenced by the virtual character’s gender, probably due to different expectations towards a male or female interaction partner. Finally, RFRs and emotional experience were more pronounced if the virtual character turned to the subjects, resulting in mutual eye-to-eye contact. These results are in line with recent results by Bourgeois and Hess (2008) suggesting that RFRs are not reflex-like mechanisms but serve as an affiliative signal that has important functions for social interaction.

REFERENCES


² Analysis of the responses to a short follow-up questionnaire revealed that, despite the cover story, 45% of the subjects had adequate ideas about the EMG electrode’s true purpose.


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