Virtual Social Interactions in Social Anxiety—The Impact of Sex, Gaze, and Interpersonal Distance

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Abstract

In social interactions, interpersonal distance between interaction partners plays an important role in determining the status of the relationship. Interpersonal distance is an important nonverbal behavior, and is used to regulate personal space in a complex interplay with other nonverbal behaviors such as eye gaze. In social anxiety, studies regarding the impact of interpersonal distance on within-situation avoidance behavior are so far rare. Thus the present study aimed to scrutinize the relationship between gaze direction, sex, interpersonal distance, and social anxiety in social interactions. Social interactions were modeled in a virtual-reality (VR) environment, where 20 low and 19 high socially anxious women were confronted with approaching male and female characters, who stopped in front of the participant, either some distance away or close to them, and displayed either a direct or an averted gaze. Gaze and head movements, as well as heart rate, were measured as indices of avoidance behavior and fear reactions. High socially anxious participants showed a complex pattern of avoidance behavior: when the avatar was standing farther away, high socially anxious women avoided gaze contact with male avatars showing a direct gaze. Furthermore, they showed avoidance behavior (backward head movements) in response to male avatars showing a direct gaze, regardless of the interpersonal distance. Overall, the current study proved that VR social interactions might be a very useful tool for investigating avoidance behavior of socially anxious individuals in highly controlled situations. This might also be the first step in using VR social interactions in clinical protocols for the therapy of social anxiety disorder.

Introduction

In social interactions, people automatically and reliably regulate the distance maintained between themselves and others. The area individuals maintain around themselves, into which intrusion by others causes discomfort and heightened arousal, is called personal space. This interpersonal distance regulates arousal in communications, but also serves as a protective buffer such that a larger interpersonal distance is kept when the perceived risk of a threat is high. Furthermore, it protects from overstimulation or over-arousal. Personal space is used in nonverbal communication to reflect intimacy, and is expressed and regulated by non-verbal behavior like interpersonal distance and eye gaze.

The research on personal space has mostly relied on the use of confederates. In these studies, participants were asked to indicate when an approaching confederate has to stop, or they were asked to approach the confederate and stop when they started to feel uncomfortable. Another paradigm is the chair-selection paradigm, where participants were asked to select a chair in a row, where one confederate was already seated. The distance between the selected seat and the confederate was taken as an index of personal space. In this line of research, it was found that age, attractiveness, cultural influences, and personality factors like extraversion have different influences on personal space. Most important, sex differences were found, such that men compared to women keep a bigger interpersonal distance to same-sex interaction partners. However, the empirical results concerning the different variables and their influence on personal space are very inconsistent. Most likely, methodological differences across studies and the problems inherent in the usage of confederates may account for most of the variance.

An important variable influencing interpersonal distance, however, seems to be the gaze direction of the potential interaction partner. According to equilibrium theory, there is a reciprocal dependence between gaze and personal space in social interactions. If the interaction partner intrudes an individual’s personal space, she will avoid mutual gaze to regulate the level of arousal and intimacy. However, if the interpersonal distance is larger, mutual gaze is more likely to be expressed. The predictions of this theory have been...
confirmed in several studies. In these studies, a dramatic reduction in gaze in response to invasion of personal space was shown. Furthermore, it was demonstrated that participants increase personal space between themselves and confederates who increased mutual gaze. In another empirical study, it was found that participants who had to intrude the personal space of one of two confederates were more likely to approach the one exhibiting no mutual gaze. 

In sum, there is evidence that gaze and personal space are closely interlinked. However, the empirical studies conducted so far are rare, most likely because good experimental control of social interactions is difficult to accomplish. Notably, most of the research on personal space was done before the mid-eighties. After that, there has been a remarkable decrease in research interest in interpersonal space. This is most likely because there were weaknesses in the methodologies employed to measure interpersonal distance. Serious concerns have been raised in terms of ecological validity and of unreliability or inaccuracy of the obtained measures.

Recently, the application of new technologies like virtual reality (VR) in the study of social processes has been successfully demonstrated. VR allows good experimental control while maximizing ecological validity. Thus VR as a research tool to investigate social interaction processes might allow for high experimental control, but also realization of close-to-real-world conditions in the experimental setting. Most important, variables like gaze direction or sex of the interaction partner can be systematically and independently manipulated, which can hardly be done in vivo. Furthermore, behavior like eye and head movements or interpersonal distance between interaction partners can be easily measured within VR using eye- and head-tracking. This would allow, for instance, obtaining direct measures of approach and avoidance behavior in social interactions. Recent experiments in VR confirmed the feasibility of this technology in research on social processes by replicating findings on social facilitation/ inhibition, conformity, and interpersonal distance. Concerning social interaction and personal space, it was found that gaze and other variables, such as agency, influence personal space. In this study, participants were immersed in a scenario where they had to approach a virtual character, pass by, and read a letter written on the back of the avatar. It was demonstrated that participants kept a larger distance from the virtual character when the character showed a direct gaze. In a similar experiment, it was observed that participants kept a larger interpersonal distance from the virtual character the more realistic it looked. Recently, VR was also used to investigate interpersonal distance in patients suffering from schizophrenia, where it was found that patients kept larger distances than controls when confronted with a virtual person. Overall, the studies mentioned above show that VR is suitable to investigate social-interaction processes, and might overcome some of the issues inherent in experimental research on social interaction in the lab. Furthermore, as the study in schizophrenia patients showed, VR might be especially useful in investigating social interactions in clinical disorders, as patients might be more compliant to a virtual rather than a real exposition.

Regarding the treatment of anxiety disorders with VR exposure therapy, outcomes so far have been highly promising, with the effects of VR exposure comparable to in vivo exposure therapy. Research from our own group showed that VR therapy is highly effective in the treatment and assessment of specific phobias like fear of flying and spider phobia. However, the VR therapy studies in social anxiety have mostly used the scenario of a fear of public speaking, where the patient is immersed in a virtual public-speaking task. Despite quite promising results, the fear of public speaking is a highly selective scenario, and patients suffering from broader fears of social interaction might not benefit from this treatment. Thus the development of different VR scenarios involving social encounters is clearly needed.

Social anxiety is characterized by an extensive fear of being evaluated by others. Consequently, social encounters are threatening situations for high socially anxious people; they cause physical and psychological symptoms of fear, and are therefore avoided. However, in everyday life, social interactions can hardly be avoided in general. Thus highly anxious people show more subtle avoidance behavior in these situations, such as avoiding eye contact. The research on the avoidance behavior of socially anxious individuals in social interactions is, however, so far scarce. Most research has been conducted on gaze behavior during social interactions. While it has been reported that, in interviews, high socially anxious people show less eye contact than the low socially anxious, no such differences have been reported in other experimental studies where interaction was simulated using video clips or still pictures of potential social-interaction partners. Even less is known about how social anxiety is related to interpersonal distance. Although it has been found that there is a positive correlation between levels of anxiety and interpersonal distance, empirical studies in the socially anxious are to our knowledge missing. In an early study, it was found that, in an anxiety-inducing situation relative to a low stress situation, interpersonal distance was significantly increased.

Given the extensive fear of being evaluated by others in social situations, one would clearly predict that socially anxious people have a larger personal space, that is, they already feel uncomfortable at relatively larger interpersonal distances compared to low socially anxious people. This should even be more pronounced if the interaction partner shows a direct gaze, as a direct gaze is a clear signal of being under someone else’s attention. In the present study, we manipulated gaze and interpersonal distance in a virtual social interaction. Virtual characters (avatars) approached participants, stopped either some distance away (1.5 m) or closer to the participant (0.5 m), and showed either a direct or an averted gaze. To this end, we investigated the impact of gaze, sex, and interpersonal distance on avoidance behavior (mutual gaze, head movements) and heart-rate (HR) activity in high and low socially anxious students. It was assumed that high socially anxious participants would show a greater degree of avoidance behavior (avoiding eye contact with the avatar, backward head movements) and increased HR accelerations to the avatars as an index of a phobic defensive reaction. This innovative approach consisted of using VR techniques to model social interactions realistically and thus obtain a high degree of ecological validity.

**Method**

**Participants**

A total of 162 female students from the University of Würzburg were screened for social anxiety by means of the
Table 1. Group Characteristics

<table>
<thead>
<tr>
<th>Variable</th>
<th>LSA (n = 20)</th>
<th>HSA (n = 19)</th>
<th>t(37)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>22.3 ± 2.3</td>
<td>21.9 ± 2.4</td>
<td>0.5</td>
<td>0.59</td>
</tr>
<tr>
<td>BFNE</td>
<td>32.3 ± 7.1</td>
<td>48.1 ± 5.3</td>
<td>7.8</td>
<td>0.01</td>
</tr>
<tr>
<td>SPAI</td>
<td>67.0 ± 13.1</td>
<td>88.6 ± 21.7</td>
<td>3.4</td>
<td>0.01</td>
</tr>
<tr>
<td>STAI-Trait</td>
<td>35.7 ± 7.0</td>
<td>46.1 ± 9.9</td>
<td>3.9</td>
<td>0.01</td>
</tr>
<tr>
<td>STAI-State</td>
<td>36.1 ± 5.8</td>
<td>36.9 ± 5.9</td>
<td>0.5</td>
<td>0.67</td>
</tr>
<tr>
<td>EPQ (extraversion)</td>
<td>7.8 ± 3.0</td>
<td>6.8 ± 3.9</td>
<td>0.9</td>
<td>0.39</td>
</tr>
<tr>
<td>EPQ (psychoticism)</td>
<td>2.8 ± 2.0</td>
<td>2.2 ± 1.1</td>
<td>1.1</td>
<td>0.27</td>
</tr>
<tr>
<td>EPQ (neuroticism)</td>
<td>4.1 ± 2.6</td>
<td>7.6 ± 2.8</td>
<td>4.0</td>
<td>0.01</td>
</tr>
<tr>
<td>IPQ (total)</td>
<td>2.5 ± 1.5</td>
<td>1.8 ± 1.5</td>
<td>1.4</td>
<td>0.19</td>
</tr>
</tbody>
</table>

*The German scores of the Social Phobia and Anxiety Inventory (SPAI) were transformed into the original scores.

In the virtual environment, participants were confronted with 8 different partners (4 male, 4 female) with different hairstyles and hair colors, and clothes. All of the avatars showed a mildly positive facial expression. The avatars walked toward the participant, and stopped at either 0.5 meters or 1.5 meters in front of the participant. The two different avatar gaze conditions consisted of either a direct or an averted gaze. A direct gaze was operationalized by mutual eye contact of avatar and participant. For the averted-gaze condition, the avatar was programmed to look at the middle area of the subjects’ upper body to resemble a lowered gaze (see Figures 1b and c for examples). Overall, 32 trials were presented (eight avatars×four conditions) per distance condition.

During the session, the electrocardiogram (ECG) was continuously recorded using a Vitaport 1 System (Becker Meditec, Karlsruhe, Germany) at a sampling rate of 384 hertz. During the approach of the avatar, the distance between participant and avatar was continuously recorded by the head-tracking system. The subjects’ eye movements were also monitored continuously by a ViewPoint Eye Tracker (Arrington Research Inc., Scottsdale, AZ) at a sampling rate of 60 hertz.

**Procedure**

After arriving at the laboratory and signing the informed consent form, participants completed the questionnaires as mentioned above. Afterward, the electrodes for the ECG were attached, and the HMD was mounted and adjusted to the participants’ vision. A calibration procedure for the eye tracking was performed, and then the experimental session started. Participants were guided to the start position within the virtual room, and after instructions given via text on the screen and earphones, the experimental trials started. In each trial, the avatar started to move toward the participant (2 sec). Then the avatar stopped either at a distance of 1.5 meters (far condition) or 0.5 meters (close condition), and the avatar started to show either a direct or an averted gaze (see Figures 1B and C). The avatar remained in its final position for 6 seconds. Finally, an intertrial interval (ITI) of 3 seconds with a blank screen was presented, where the participant was asked to stare at a cross in order to reset the head position, after which the next trial was started.

**Data reduction and statistical analyses**

Changes in heart rate were determined by subtracting the activity in the 1 second before the trial started from that

German version of the Brief Fear of Negative Evaluation scale (BFNE). The lowest scoring 20% (referred to as low socially anxious, LSA) and the highest scoring 20% (referred to as high socially anxious, HSA) were eligible to take part in the study. Out of this pool of potential participants, a total of 39 (20 LSA, 19 HSA) participants completed the experimental session and were taken into analysis. Before the experimental session, the participants completed the German version of the Eysenck Personality Questionnaire (EPQ-RK), the State–Trait Anxiety Inventory (STAI), the Social Phobia and Anxiety Inventory (SPAI), and the BFNE again to check for test-retest reliability, which manifested in a Cronbach’s alpha of 0.90. Furthermore, participants were asked to complete questionnaires on cybersickness and presence within virtual reality. The mean age and mean questionnaire scores are reported in Table 1. As expected, the groups differed in terms of social anxiety (BFNE, SPAI, see Table 1). Furthermore, groups also differed in trait anxiety and neuroticism, with HSA scoring higher on both measures. No differences between groups were found in age, state anxiety, positive and negative affect, psychoticism, social desirability, extraversion, cybersickness, and perceived presence in VR. All participants were without any history of psychiatric or neurological disorder (self-report), and all participants reported normal or corrected-to-normal vision and were unmedicated. For their participation, the subjects each received 16€.

**Stimulus materials and apparatus**

The software CyberSession, which was used to manipulate and control the virtual environments during the experiment, was written in-house. The rendering was completed by the Source Engine (Valve Inc., Bellevue, Washington, DC). The virtual environment was displayed via a head-mounted display (HMD; Z800 3D Visor; eMagin Inc., Bellevue, Washington, DC). The head position of the participants was continuously monitored with an electromagnetic tracking device (Fastrack System and Long Ranger extension; Polhemus, Colchester, VT) in order to adapt the field of view to head movements and to assess head orientation and movements. Instructions were given verbally via earphones accompanied by texts on the screen. The virtual room presented via the HMD was designed to look like the real laboratory where the experimental session took place. The virtual room corresponded to 4×3 meters, and both sidewalls had a doorway (see Figure 1). The start position of the virtual social-interaction partner (avatar) was in the middle of one end of the room, whereas the position of the subject was at the opposite end of the room, facing the avatar. The initial distance between avatar and subject corresponded to approximately 3.4 meters (see schema in Figure 1A). To get participants used to the VR conditions, they were asked to explore the virtual room prior to the start of the trials (without any avatars present). Four male and four female avatars were used. They all had different hairstyles and hair colors, and clothes. All of the avatars showed a mildly positive facial expression. The avatars walked toward the participant, and stopped at either 0.5 meters or 1.5 meters in front of the participant. The two different avatar gaze conditions consisted of either a direct or an averted gaze. A direct gaze was operationalized by mutual eye contact of avatar and participant. For the averted-gaze condition, the avatar was programmed to look at the middle area of the subjects’ upper body to resemble a lowered gaze (see Figures 1b and c for examples). Overall, 32 trials were presented (eight avatars×four conditions) per distance condition.

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occurring during the 6 seconds of the avatar standing still showing either an averted or a direct gaze. The ECG was recorded by two large SensorMedics electrodes placed on the sternum and the left lateral margin of the chest and a ground electrode attached to the left lower coastal arch. R-waves of the continuous raw ECG signal were detected by an algorithm using Vision Analyzer software (BrainProducts, Munich, Germany), the interbeat intervals were computed and then converted into heart rate.\(^4\) Mean heart-rate responses were scored by averaging the HR for each participant and each trial across the 6 seconds of the avatars standing still. The second before the start of the trial was used as a baseline and subtracted from the mean values.

The head movements were analyzed as the mean deviation within the 6 seconds of each condition and a subtracted baseline before the start of the trial. To this end, positive values index a relative head movement forward (approach), whereas negative values index a relative movement backward (avoidance).

The continuous eye movements were analyzed as relative fixation durations in predefined areas of interests (AOI). These were defined by a rectangle around the eye zone, including the eyebrows of the avatar. Different hit zones were calculated for male and female avatars because of different facial structures and body sizes. This relative value corresponds to the time the participant looked at the eye region of the avatar relative to the overall duration of the trial.

All parameters described above were averaged per condition and were analyzed by mixed repeated measures analyses of variance (ANOVAs) containing the between-subject factor group (2: LSA vs. HSA), sex of the avatar (2: male vs. female), distance (2: close vs. far), and gaze direction of the avatar (2: direct vs. averted). Significant interactions were followed up with planned contrasts. In case the factor group was a factor in the interaction, separate ANOVAs for each group were calculated. All statistical analyses used the 5% level of statistical significance. Degrees of freedom were adjusted, when appropriate, using the Greenhouse–Geisser correction.

**Results**

**Eye-movement data**

The statistical analysis of the mean duration, when the participants looked at the eye region of the avatar, was conducted separately for the far (1.5 m) and the close (0.5 m) distance conditions, as the size of the areas of interest differed considerably for each condition.

**Far distance**

For the far distance condition, a significant three-way interaction of the sex of the avatar × gaze direction × group was found, \(F(1, 37) = 5.67, p = 0.023, \eta_p^2 = 0.13\). To disentangle this interaction further, follow-up ANOVAs were conducted for each group separately. No effects were found in LSA. In HSA, a significant sex of the avatar × gaze direction interaction was revealed, \(F(1, 18) = 6.91, p = 0.017, \eta_p^2 = 0.28\). Separate \(t\) tests for each gaze direction revealed that this was due to a longer fixation time on female compared to male faces in the direct gaze condition, \(t(18) = 2.18, p = 0.043\), whereas no effects of sex were detected in the averted gaze condition, \(t(18) = 1.09, p = 0.290\). Additionally, a significant difference for male avatars between the direct and the averted gaze conditions was found: the eye regions of male avatars with a direct gaze were fixated less than the eye region of male avatars with an averted gaze, \(t(18) = 3.07, p = 0.007\) (see Figure 2).

**Close distance**

For the close distance condition, the statistical analysis revealed a significant main effect of sex of the avatar,
F(1, 37) = 37.17, p < 0.001, ηp² = 0.50, and the interaction of sex of the avatar × gaze direction F(1, 37) = 15.44, p < 0.001, ηp² = 0.29. All participants fixated the eye region of male avatars showing a direct gaze less than the avatars with an averted gaze, t(38) = 3.62, p = 0.001, whereas they looked at the eye region of female avatars longer in the direct compared to the averted gaze condition, t(38) = 2.14, p = 0.039. Fixation duration did not differ between high and low socially anxious participants (Figure 3).

Posture of head

The overall ANOVA of the mean head posture revealed significant main effects of the sex of the avatar, F(1, 37) = 19.80, p < 0.001, ηp² = 0.37, indicating a larger avoidance reaction (backward movement) in response to male compared to female avatars. More interesting, the three-way interaction of group × sex of the avatar × gaze direction was highly significant, F(1, 37) = 12.10, p = 0.001, ηp² = 0.25. To break down this interaction, separate ANOVAS for each group were calculated. For LSA participants, a significant main effect of the sex of the avatar, F(1, 19) = 6.26, p = 0.022, ηp² = 0.25, and its interaction with the gaze direction of the avatar were found to be significant, F(1, 19) = 8.90, p = 0.003, ηp² = 0.32. LSA showed more approaching behavior (forward head movement) to female avatars compared to a direct gaze. However, in HSA the main effect of the sex of the avatar, F(1, 18) = 14.24, p = 0.013, ηp² = 0.44, and the two-way interaction of the sex of the avatar × gaze of avatar also reached significance, F(1, 18) = 4.72, p = 0.043, ηp² = 0.21. They receded more from male avatars showing a direct gaze and approached female avatars showing a direct gaze more, t(18) = 4.44, p < 0.001. Furthermore, HSA receded more from male avatars showing a direct compared to an averted gaze, t(18) = 2.55, p = 0.020 (see Figure 4).

Heart-rate measures

For the mean HR changes during the confrontation with the avatar, statistical analyses revealed a significantly larger deceleration in response to the close compared to the far avatar, F(1, 37) = 6.81, p = 0.013, ηp² = 0.16, and to avatars showing a direct compared to an averted gaze, F(1, 37) = 4.90, p = 0.033, ηp² = 0.12. However, these effects were further qualified by a significant three-way interaction of the sex of the avatar × distance of the avatar × gaze direction, F(1, 37) = 7.41, p = 0.010, ηp² = 0.17. This interaction was decomposed by separate post-hoc analyses for both of the distance conditions. In the near distance condition, a significant sex of the avatar × gaze interaction was found, F(1, 37) = 4.06, p = 0.050, ηp² = 0.10. Male avatars showing a direct gaze elicited larger HR decelerations (M = −2.37, SD = 2.21) compared to an averted gaze (M = −1.49, SD = 2.24), while in the female avatars, no differences emerged between a direct and an averted gaze (M = −2.05, SD = 2.41; M = −2.41, SD = 2.28 respectively). In the far distance condition, male avatars (M = −1.87, SD = 1.93) elicited a significant larger HR deceleration compared to female avatars (M = −1.29, SD = 1.87), F(1, 37) = 4.65, p = 0.038, ηp² = 0.11. Furthermore, a direct gaze was associated with a larger HR deceleration (M = −1.94, SD = 1.66) compared to an averted gaze (M = −1.22, SD = 2.27), F(1, 37) = 4.72, p = 0.036, ηp² = 0.11 (M = −2.37, SD = 2.21). Overall, no significant effects involving social anxiety were found.

Discussion

In the present study, avoidance behavior and physiological responses to virtual social interactions were investigated in
high and low socially anxious female students. Regarding the behavioral measures, clear signs of an impact of the sex and the gaze behavior of the virtual interaction partner on avoidance behavior in the high socially anxious were found. When the avatar was standing farther away, high socially anxious women avoided gaze contact with male avatars showing a direct gaze when compared to female avatars and male avatars showing an averted gaze. This means that already in the farther away condition (1.5 m), which is considered borderline between personal and social space, the sex and the gaze behavior influences high socially anxious people, such that they avoid looking at male direct-gazing avatars, whereas in this condition no effects were observed in the low socially anxious. This is further supported by the head-movement data. High socially anxious participants showed more pronounced avoidance behavior (backward head movements) in response to male avatars showing a direct gaze, regardless of the interpersonal distance. In contrast, low socially anxious participants showed approach behavior to female avatars with an averted gaze. Regarding HR measures, no differences between high and low anxious participants were observed. However, stronger HR deceleration was found in the close condition in response to male direct-gazing avatars, whereas in the farther away condition, a direct gaze elicited more pronounced HR deceleration compared to an averted gaze, and male avatars elicited stronger HR deceleration compared to female avatars. These results show that for female subjects, male interaction partners with a direct gaze are of special relevance and elicit larger orienting responses. In general, a greater heart-rate deceleration indicates greater attention devoted to an interesting, meaningful, or novel visual stimulus. In emotion research, it was found that aversive pictures elicit a greater heart-rate deceleration than positive pictures, except when the material is truly phobic to the viewer. As we did not find any signs of cardiac acceleration as a sign of a defensive reaction in high socially anxious participants, one may conclude that these stimuli are of special relevance, attract the attention, but are not truly threatening for the high socially anxious participants. This might be due to the non-clinical levels of social anxiety investigated in our sample. However, these findings are also in line with studies showing that the high socially anxious often do not differ from the low socially anxious in terms of their physiological reactions to social stimuli.

To our knowledge, this is the first study where immersive VR was systematically used to investigate social interactions in socially anxious people. It has been demonstrated that virtual social interactions were modeled successfully, as some results on the interaction of gaze direction and mutual distance were replicated. For example, in the close condition, all participants showed less eye contact to male avatars with a direct gaze, which is in line with studies showing that women tend to avoid mutual gaze with male interaction partners. This was accompanied by stronger HR decelerations in response to male direct-gazing avatars, indicating larger orienting responses to male avatars.

Considering the differences between high and low socially anxious participants, it was shown that high socially anxious women already seem to differentiate more elaborately the approaching interaction partner at the farther distance, which might indicate a larger personal space. For them, even at a relatively far distance, the approaching avatar might reflect a potential threat, and as the gaze behavior indicates, male interaction partners with a direct gaze are of special relevance. Based on the distinction of Hall, the farther away condition (1.5 m) in the present study corresponds to the transition from the more formal, social zone to the more personal zone, whereas the close condition (0.5 m) corresponds to the borderline personal to intimate zone. As there were only differences found for the farther away zone, this might show that social anxiety is associated with reactions to violations of personal space at a farther away condition, whereas the violation of personal space in an almost intimate distance is uncomfortable for everybody, and thus social anxiety does not play a prominent role. Interestingly, the violation of personal space elicited avoidance behavior (backward head movements) only in the socially anxious and most prominently to male intruders showing a direct gaze. This further supports the notion that social anxiety (at least in women) is associated with fear of social encounters with the
opposite sex, and that a direct gaze enhances this fear. Overall, this is in line with a study that found that participants with higher levels of social anxiety were significantly more likely to avoid “disturbing” virtual characters in a virtual environment.\textsuperscript{44}

The data on gaze behavior also nicely corroborate the predictions from equilibrium theory,\textsuperscript{3} such that in the close condition, a clear compensation is seen in all participants with gaze avoidance of a direct compared to an averted gaze of male avatars. This is in line with field as well as VR studies showing this nonverbal behavior, which aims at maintaining the degree of intimacy that is most comfortable.\textsuperscript{9,14,16,45} This replication further supports the view that modeling social interactions in VR is a suitable research tool for clinical as well as basic research questions. Given the good success rates of VR based exposure therapy in anxiety disorders,\textsuperscript{20,46} the present VR scenarios might also serve as part of a behavioral therapy in social anxiety disorder. Thus further improvements in modeling virtual social interactions are needed to implement these VR scenarios in exposure therapy.

Given the growing interest in the neural correlates of social anxiety and the processing of social stimuli, VR might serve as an excellent option for investigating social interaction, personal space, and its correlates in MRI scanners. Recently, it has been shown that the amygdala has a key function in mediating the regulation of interpersonal distance and space.\textsuperscript{47} Given the findings from research on face processing in social anxiety, which point at heightened amygdala activity in response to faces in general,\textsuperscript{48} one might speculate that hyperactivity of the amygdala in socially anxious people in response to faces might also be present for social stimuli like approaching people. Thus enhanced avoidance reactions to violations of personal space, as shown in the present study, might also be mediated by this amygdaloid hyperactivity in the socially anxious. However, further neuroimaging research is clearly needed to shed light on the underlying brain mechanisms of heightened responses to personal space violations as reported in the present study. The VR technology used here might be an excellent option to investigate the neural correlates of personal space in an MRI scanner, enabling social interactions to be simulated in the restricted environment of an MRI.

In sum, the present study successfully demonstrated that VR can be used to model and investigate social interactions in a more standardized but highly ecological way. This technology might lead to a revitalization of the research on personal space, which has been almost stopped for the last 25 years because of the methodological issues mentioned above. Furthermore, and mostly important in the clinical context of the present research, this allows the investigation of social interactions in clinical disorders like social anxiety, about which little so far is known. In the future, VR scenarios like these might serve as a therapeutic tool for the treatment of disorders, which are associated with problems in social interactions such as social anxiety, autism, and so on.

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**Disclosure Statement**

No competing financial interests exist.

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