Social VR: How Personal Space is Affected by Virtual Agents' Emotions

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Figure 1: A user indicates his personal space preferences while being approached by a virtual agent (VA). When the VA is at a comfortable distance, the user triggers a first designated command (green barrier). When the VA reaches the user's uncomfortable distance, the user triggers a second designated command (red barrier), which stops the VA immediately.

Abstract

Personal space (PS), the flexible protective zone maintained around oneself, is a key element of everyday social interactions. It, e.g., affects people's interpersonal distance and is thus largely involved when navigating through social environments. However, the PS is regulated dynamically, its size depends on numerous social and personal characteristics and its violation evokes different levels of discomfort and physiological arousal. Thus, gaining more insight into this phenomenon is important.

We contribute to the PS investigations by presenting the results of a controlled experiment in a CAVE, focusing on German males in the age of 18 to 30 years. The PS preferences of 27 participants have been sampled while they were approached by either a single embodied, computer-controlled virtual agent (VA) or by a group of three VAs. In order to investigate the influence of a VA's emotions, we altered their facial expression between angry and happy. Our results indicate that the emotion as well as the number of VAs approaching influence the PS: larger distances are chosen to angry VAs compared to happy ones; single VAs are allowed closer compared to the group. Thus, our study is a foundation for social and behavioral studies investigating PS preferences.

Index Terms: I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism—Virtual Reality; J.4 [Computer Applications]: Social And Behavioral Sciences—Psychology

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1 Introduction

Gaining insight into human behavior in everyday social work and leisure situations is elementary for both basic and applied research. Psychology, for instance, traditionally focuses on understanding human behavior and applying this knowledge to fields such as mental health care. In computer science, understanding human behavior and being able to simulate it is crucial for the design of advanced (emotional) human interfaces, especially in the area of social virtual reality (VR). Here the human interfaces are commonly represented by means of embodied, computer-controlled characters, so-called virtual agents (VAs), whose behavior has to meet the expectations raised due to their human-like appearance.

In order to investigate social human behavior two experimental settings are typically used: a) field experiments in a natural frame with actors representing potential interaction partners and b) laboratory experiments. Both approaches, however, have shortcomings. Field experiments often lack experimental control; especially human interaction partners will not show the exact same behavior throughout a dynamic interaction. Similarly, there is less control over other variables that might influence the results. In contrast, laboratory experiments often rely on artificial tasks and contexts. Furthermore, interaction partners might be depicted only by 2D icons while the interactions are mostly reduced to abstract keyboard and mouse input. Both aspects limit the ability to generalize the results to real-life interactions.

By combining the advantages of both experimental settings, VR overcomes the aforementioned drawbacks and thus enlarges the methodological toolbox of social and behavioral studies [7, 12]. By means of VR-displays, such as HMDs or CAVEs, participants are completely immersed into a virtual scene. They still can interact with and navigate through the respective scene by natural behavior, feeling a high degree of presence, i.e., the illusion of actually being in the virtual world. Importantly, participants respond realistically when experiencing a plausible, safe, and controllable VR scenario (e.g., [35, 38]). Furthermore, the social interaction partners can be represented by VAs, allowing a reproducible, yet adaptable behavior of the virtual counterparts. This allows to unequivocally establish who is influencing whom (see the so-called reflection problem [29]). Consequently, VR-experiments have an almost natural frame while researchers retain maximum control over the experiment and can observe non-confounded interaction effects, which makes them increasingly attractive for psychological research [8, 43].

In this work, we focus on the concept of personal space (PS), defined as a flexible protective zone maintained around oneself [17] in real-life situations [15]. This nonverbal behavior is, e.g., largely involved when navigating through a social environment, and it affects the distance people keep to others. Previous research has shown that the concept of PS is also applicable to VR scenarios. Users, for instance, keep a PS around their own representation in Second Life [14] and they respect a VA's PS [4, 5] while keeping smaller distances to virtual objects than to virtual humans [3].

Based on larger PS preferences to angry-looking individuals obtained in real-life situations [42], we investigated the influence of a VA's emotional facial expression E on PS preferences. A VR-based experiment was conducted in which each VA showed either an angry (E_a) or a happy (E_h) facial expression. Participants were approached by either a single VA or a group of three VAs in six treatments described as triplets [VA_1, VA_2, VA_3] giving either the VAs' emotion shown by their facial expressions or a '_' if no VA was present. Two conditions describe the single-agent-conditions with either an angry [_ ,E_a, _] or a happy [_ ,E_h, _] emotion while the four remaining treatments describe group-conditions: two conditions with three VAs showing the same facial expression, defined as congruent conditions ([E_a,E_a,E_a], [E_h,E_h,E_h]), and two so-called incongruent conditions with two VAs showing an identical emotion framing the one with a different emotion ([E_h,E_a,E_h], [E_a,E_h,E_a]).

As violations of an individual's PS may trigger aggressive reactions of the offended person [34], the insight gained from our study is an important initial step towards new and innovative VR-based research on aggressive behaviors. Furthermore, the new insight will support the efforts in developing generic algorithms modeling a more human-like VA-behavior in terms of interpersonal distance.

The remainder of this paper is structured as follows: Section 2 provides a brief insight into the knowledge already gained on PS. In Section 3 the design and setup of the user study are described. The results are given in Section 4 and are discussed in Section 5. Finally, a conclusion is given in Section 6.

2 Insights into Personal Space

PS is regulated dynamically, ranging from 'intimate' (0 - 45 cm), 'personal' (45 - 120 cm), 'social' (120 - 360 cm) to 'public' (> 360 cm) zones [17], which reflect the type of relationship a person has to others. Thus, the PS is considered as a non-verbal communication channel [2] as well as a personal 'safety zone'. Violations of the PS typically evoke discomfort and physiological arousal [18] and can trigger avoidant or aggressive reactions [34].

As a key element of social interactions, PS is a recurring subject of investigations. The findings show that PS is typically shaped elliptically with about twice as much space in one's front area compared to one's back and sides [2]. Furthermore, its exact size and shape depends on environmental factors, e.g., obstacle movements [16], as well as on numerous social and personal characteristics. Examples thereof are the nature of the relationship between the persons and the other's gender and age [2, 22].

Affective expressions also influence PS preferences as larger distances are kept to angry-looking individuals [42]. In our everyday life, we infer others motivational and emotional states not only via their facial expressions but also via a plethora of non-verbal cues, such as eye gaze and body orientation. This wealth of influencing factors presents a challenge for balancing experimental with ecological validity when studying such a dynamic concept as PS. Therefore, experimental research mainly relies on (computerized) stop-distance paradigms, in which actors approach the subjects until they report feeling uncomfortable [23, 36]. Given the dynamic nature of social interactions and the subtle affective signals that can hardly be controlled, using real humans as interaction partners is likely to compromise experimental control, in particular reliability. In contrast, desktop-based computerized stop-distance paradigms, in which subjects drag virtual space invaders towards their own virtual representation, have the drawback of providing only an abstract third-person view onto the social environment.

Immersive virtual environments are crucial in overcoming this lack of direct, first-person experiences by constructing natural frames while maintaining maximal experimental control. They provide a valid assessment of PS preferences as similar effects have been shown for interacting with virtual and real-life interaction partners [22]: As in real social interactions [32], immersed individuals maintain a greater interpersonal distance to VAs showing a more realistic gaze behavior, e.g., mutual gaze, than to those who did not [4, 5]. Furthermore, a significant correlation between PS and gaze behavior for female individuals was found [5], providing evidence for gender as influencing characteristic. When being approached by a VA, individuals tend to move away, avoiding collisions in order to maintain their 'safety zone' [5]. Furthermore, a higher skin conductance of individuals who are approached by a group of VAs compared to a single VA are found, indicating a relationship between the physiological arousal and number of VAs in the same distance [28].

If individuals approach a VA, they expect a noticeable reaction on their presence by the VA, e.g., by making eye contact with the individual [9, 21, 31]. Besides, they expect the VA to take responsibility for or at least collaborate in collision avoidance to maintain the individual's PS [9, 31]. Additionally, the PS' elliptical shape has been verified [3].

However, to the best of our knowledge, VR-based experiments have not yet taken emotional expressions of the VA into account. We address this gap by presenting results of a first study in which participants' PS preferences were sampled by means of either a single VA or a group of three VAs approaching the participants showing two emotional states: angry and happy. The basic setting, an approaching single VA or an approaching group, is thereby comparable to the aforementioned design of Llobera et al. [28]. While they focus on the change in skin conductance while VAs approach an individual to three fixed distances (one intimate, one personal and one social distance), we favored a subjective indicator of proxemics for this first study. By asking our participants explicitly to stop the approaching VAs directly at a too uncomfortable distance, we are able to sample the PS preferences. Adding psycho-physiological indicators like skin conductance and heart rate as additional implicit measurements is planned for follow-up studies.

3 User Study

We conducted a within-subject user study in a CAVE to investigate the influence of emotions shown by means of facial expressions of VAs on participants' PS preferences. As gender and age are influencing factors for PS preferences [2], we limited our participants to German, 18-30 year-old males (see Sec. 3.6). Their task was to indicate their comfortable and uncomfortable distance via designated commands while being approached successively from five directions by either a single VA or a group of three VAs.

3.1 Hypotheses

We tested the following hypotheses:

H1 *Participants show PS preferences comparable to real-life situations, with an elliptically-shaped PS especially for an uncomfortable distance.*
VR-based experiments conducted by, e.g., Bailenson et al. [4] already indicated the elliptical shape of PS. Thus, we expect that these findings also hold in our setup.

H2 *Participants keep a larger distance to VAs showing an angry emotion compared to those showing a happy emotion.*
This hypothesis is based on observations in real-life situations giving evidence that individuals tend to keep larger distances to others showing a negative facial expression [39]. More precisely, a larger distance is kept to people with angry facial expressions compared to those expressing a happy emotion [41, 42]. We expect that these findings are also observable while interacting with VAs in an immersive virtual environment (IVE).

H3 *Participants keep a larger distance to the groups of three VAs than to the single VA.*
This hypothesis is based on the findings in dynamic as well as static agent scenarios. Individuals tend to have a higher skin conductance signaling higher discomfort when being approached by a group of VAs compared to a single VA [28]. Furthermore, when agents are static, approaching individuals tend to keep larger distances to groups compared to single VAs [24]. Thus, we expect to see an influence of the number of approaching interaction partners on the individuals' PS preferences.

While the hypotheses $H1$ to $H3$ are based on previous findings, the following hypotheses $H4$ to $H6$ are explorative. We aim at investigating whether the emotion of all approaching VAs is considered equally for the PS preferences or whether certain VAs are more dominant. Thereby we distinguish between the central VA and the two framing VAs. However, we assume that all VAs will be taken into account on an equal level, so that, again, the number of emotions faced by the individual is the influencing factor. Thus we expect:

H4 *In conditions with a central angry VA, participants keep a larger distance to the congruent compared to the incongruent group.*
Combining $H2$ and $H3$, we expect to observe a larger distance to a group of three angry VAs compared to only one angry VA who is framed by two VAs showing a happy emotion.

H5 *In conditions with a central happy VA, participants keep a larger distance to the incongruent compared to the congruent group.*
Combining $H2$ and $H3$, we expect to observe a larger distance to a group with two angry VAs framing a happy one compared to a group with three happy VAs.

H6 *Participants will keep a larger uncomfortable distance to angry than to happy VAs for the central direction compared to the peripheral direction.*
This hypothesis is based on the combination of $H1$ and $H2$.

3.2 Emotions and Treatments

Our study consists of six treatments, described as a tuple of emotions E. In two treatments, only one VA is present, showing either an angry ([_, E_a, _]) or a happy ([_, E_h, _]) emotional expression. The expressions were based on Action Units of the Facial Action Coding System and optimized for the single VA, which can be seen in the left column of Figure 2. For the other four treatments, he is framed by two identical male characters, who express the same emotions, shown in the right column of Figure 2. Both emotions are static and fully blended in before the approaching phase starts.

In the two congruent conditions, all three VAs show the same emotion resulting in [E_a,E_a,E_a] and [E_h,E_h,E_h]. In the incongruent conditions, the central VA shows the eponymous emotion, while the others show the opposite one. This results in incongruent-angry [E_h,E_a,E_h] and incongruent-happy [E_a,E_h,E_a].

As discussed later, we are interested whether the position of the emotion (center or framing VA) or the number of VAs expressing a certain emotion have an impact on the individual's PS preferences. The choice of a group of three VAs was motivated by having a dedicated central position (entailing an odd number of agents) and a line constellation when VAs are approaching while allowing the participant to perceive all expressions at once.

All characters and animations used are taken from SmartBody [37]. As the toolkit only provides two male VAs in the age range of our sample we focus on, we tried to minimize the twin effect by using two different colors for the shirts of the framing VAs (see Fig. 3). This is a common approach in crowd simulations, e.g., PedVR [31].

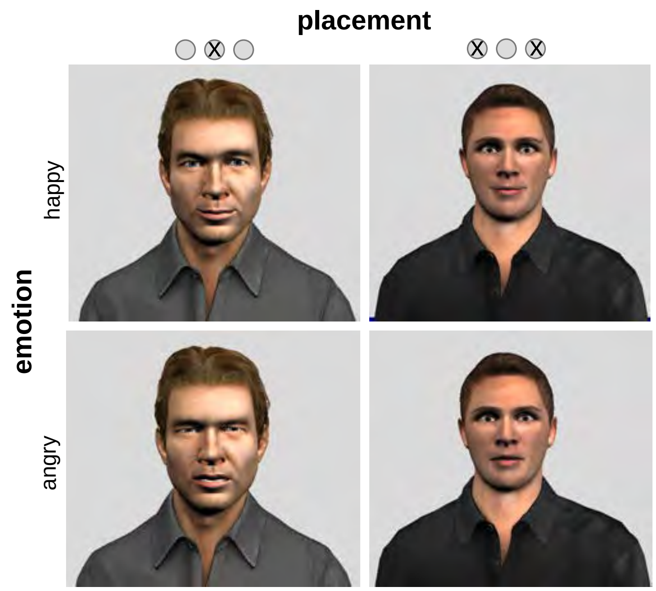

Figure 2: Emotions shown by the VAs.

3.3 Equipment

The study was conducted in a five-sided CAVE with the size $5.25m \times 5.25m \times 3.30m$ ($w \times d \times h$) providing a 360° horizontal field of regard [27]. The participants wore active stereo glasses, tracked at 60 Hz. For the interaction, an ART Flystick 2 was provided.

The CAVE's ceiling is equipped with two surveillance cameras. This allowed the supervisor to observe the immersed participant unnoticeably.

3.4 Experimental Design and Task

We chose a within-subjects design with three independent variables: (a) the *Constellation of VAs* approaching the participant (single, congruent, incongruent), (b) the *Emotions* E_a and E_h shown as facial expressions by the VAs and (c) the *Direction* from which the VAs approached. The first two result in the six treatments described in Section 3.2. The Direction causes five runs per treatment.

In each condition, a single, male participant is located in the middle of the CAVE, looking straight ahead. He is instructed to stand still and


Figure 3: The single VA is framed by two other VAs in the congruent-happy condition. The green barrier shows that the participant already indicated his comfortable distance.

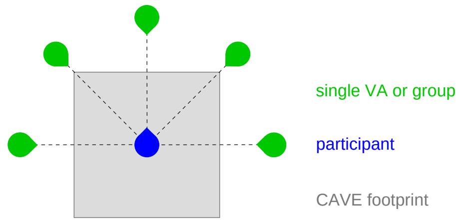

Figure 4: The five directions from which the participant is approached by either a single VA or by a group of three VAs.

is only allowed to turn his head for looking around in the scene. During each treatment, he is approached from five directions by the VAs, illustrated in Figure 4. These directions sample the frontal PS, as they are all within the participant's direct or peripheral field of view, allowing him to spot the VAs at an early stage. As no sound or visual clues for the approaching VAs were added to the study, the rear PS was not taken into account. The order of the five chosen directions is randomized.

The VAs start at a distance of 7 meters, approaching the individual at a low walking speed with about 0.8 meters per second. During this time, the VAs are directly looking at the individual, indicating their awareness of the participant's presence at an early stage. As the VAs' trajectories are straight lines towards the individual and as the scenario is a large-scale, however empty marketplace, the gazing behavior is plausible for our setting. To avoid an uncomfortable staring, animations for eye blinking are used.

While the VAs continuously approach the participant, he is asked to define two specific distances to the VAs based on his subjective perception. This process is exemplarily shown in Figure 1.

At first, the participant indicates his so-called comfortable distance. This distance is defined as the distance when he feels most comfortable for interacting with the VAs. As visual feedback, a green barrier shows up at the VAs' current positions.

The second distance is the so-called uncomfortable distance. Here, the VAs have already invaded the participant's PS and are so close that the participant feels the urgent need of stepping aside. As visual feedback, a red barrier shows up and the VAs stop immediately.

Each distance is determined by a respective button on the Flystick. On pressing the first button, the comfortable distance is logged and on pressing the second button, the uncomfortable distance. As this is a subjective measure, the button presses can happen at any time after the VAs started their approaching behavior. In case the participant does not indicate one or both distances, the VAs stop automatically 50 cm away from him. Thereby they avoid violating the participant's intimate zone, which is defined in the range of 0 - 45 cm in literature [17].

Thus, the continuous approaching of the VAs is only stopped by the participant's trigger of the uncomfortable distance or our distance regulation. Five seconds after stopping, the VAs and barriers are blended off. If there are any directions left in the treatment, the VAs are teleported to the beginning of the next direction, are blended in and the participant is again asked to specify both distances.

3.5 Procedure and Data Collection

The local ethics committee at the Medical Faculty of RWTH Aachen University approved the current study. The experimental protocol was carried out in accordance with the Declaration of Helsinki.

Prior to the study, the participants were informed about the general procedure. After giving their informed consent, they filled out a demographic questionnaire and entered the CAVE for a training phase, to learn the interaction with the Flystick. In this phase, they were approached from all directions by a single female VA. She was showing a neutral facial expression.

After finishing the familiarization phase, the user study began, consisting of the six treatments.To account for the familiarity of agents and emotions, the order of treatments was randomized.

Table 1: Means and standard deviations of the SPS [5] per treatment.

Constellation of VAs	Emotion	M	SD
Single VA	E_a	1.20	.74
	E_h	1.17	.78
Congruent Group	E_a	1.22	.71
	E_h	1.25	.70
Incongruent Group	E_a	1.25	.73
	E_h	1.22	.70

We logged different data, e.g., the participant's head orientation during the treatments as well as his specified comfortable and uncomfortable distances. Furthermore, each treatment was followed by the Social Presence Survey (SPS) [5], a questionnaire indicating the perceived social presence of the present VAs, which had to be answered inside the CAVE, using the Flystick.

After leaving the CAVE, participants filled out the Slater-Usoh-Steed questionnaire (SUS) [40], i.e, seven questions used to measure the perceived feeling of being present in the IVE.

In total, the study took about forty-five minutes per participant, from which about twenty minutes were spent fully immersed.

3.6 Participants

As gender and age are influencing factors for PS preferences (e.g., [2]), we limited our participants to 18-30 year-old males, i.e., matching the VAs' gender and age representation. Furthermore, only individuals with German as native language were selected for participation in order to keep the expectations regarding social concepts like PS requirements comparable. All participants were capable of stereoscopic vision without red-green deficiency.

Twenty-seven individuals participated in our study, recruited via Facebook and CampusLife, a website for university members, primarily students. Due to technical problems regarding the locomotion pattern of the group, we had to discard the data set of one subject. Thus, we have a sample of twenty-six participants (age: M=22.4, SD=2.22). All of them had normal motor skills and were naïve to our hypotheses.

4 Results

The proposed 7-point scales were used for the standardized questionnaires (SPS: -3=strongly disagree to 3=strongly agree [Likert scale], SUS: 1 to 7). The SPS score [5] was computed by averaging the five individual SPS ratings per VAs configuration. In order to have a consistent terminology throughout the study, we adapted the items by replacing 'person' by 'group' if applicable to the rated treatment. A repeated measures ANOVA with the two within-subject factors, Constellation of VAs (single VA, congruent group, incongruent group) and Emotion (E_a, E_h), revealed no significant effects, all Fs < 1.48, all ps $> .24$. In other words, VAs were judged as equally present across treatments. For all treatments, means were in the positive range (see Tab. 1) and differed significantly from zero (all $p_s < .008$, corrected for multiple testing). For the SUS, an average score of (M=4.15, SD=1.70) was reported, indicating a reasonably high feeling of being present in the IVE [40].

PS was indexed via the distance from the position of the (central) VA to the position of the participant. Two distances were sampled, i.e., comfortable distance (indicated by placing the green barrier) and uncomfortable distance (indicated by placing the red barrier).

Based on the supervisor's observations by means of the surveillance cameras, we know that all participants indicated both distances for all study runs. However, due to confusions of the participants which button to take for which distance indication, missing values (2.4% for comfortable distance, 3.1% for uncomfortable distance) spread across all conditions of our repeated measures design. For the follow-up studies, only one button will be used to avoid this design shortcoming. In light of listwise deletion, only a sample of $n = 9$ complete datasets could have been included in a repeated measures

ANOVA. Therefore, we decided to account for the missing values by using a mixed model, which drops only the missing observations and retains the remaining data. This enables the analysis of 761 and 756 observations for the comfortable and uncomfortable distances, respectively, which is reflected in the denominator degrees of freedom. A generalized linear mixed model with normal distribution and identity link function was applied for each distance (comfortable, uncomfortable) as the dependent variable. We structured the data as nested in Constellation of VAs (single VA, congruent group, incongruent group), Emotion (E_a, E_h) and Direction (left, left-center, center, right-center, right) and included all factors as fixed effects. Furthermore, all interactions were entered as fixed effects, and subjects were modeled as random effects. In addition to this full model, reduced models were computed, and the best-fitting model was chosen based on comparisons of the corrected Akaike Information Criteria [1] of those models. By means of the Akaike Information Criterion the quality of a set of statistical models in relation to each other is estimated.

The best-fitting model (for both distances), which ensures that the model neither under-fits nor over-fits, contained only two factors, i.e., Constellation of VAs and the interaction between Constellation of VAs and Emotion. They revealed that both had a significant effect on the distance.

Statistical analysis was performed using SPSS 22.0, and a p-value below .05 (2-sided) as indicating statistical significance. Pairwise comparisons were Bonferroni-corrected.

Furthermore, the means, standard deviations and standard errors regarding the Distance are given in meters.

4.1 Comfortable Distance

Best-Fitting Model

In the best-fitting model, there was a significant main effect of Constellation of VAs ($F_{2,755}$=66.50, p<.001) and a significant Constellation of VAs × Emotion interaction, ($F_{2,755}$=7.44, p<.001).

Follow-up comparisons of the main effect of Constellation of VAs indicated significant differences between all three Constellations, with largest distances kept from congruent groups (M=2.77, SD=.67), and smallest distances to single VAs (M=2.42, SD=.58; congruent vs. single: t(755)=11.52, p<.001). Distances to incongruent groups were in-between (M=2.59, SD=.62; incongruent vs. single: t(755)=5.84, p<.001, incongruent vs. congruent: t(755)=-6.99, p<.001).

The Constellation × Emotion interaction was due to an effect of Emotion only for the single VA (t(755)=4.02, p<.001), i.e., larger distances were kept when the VA was angry than when he was happy (see Fig. 5). In both the congruent as well as the incongruent group, the differences were not significant, all Fs < 3.27, all ps > .07.

Moreover, for angry expressions, larger distances were kept for congruent than for incongruent groups (t(755)=5.17, p<.001), and larger distances were kept to congruent groups than to a single VA (t(755)=5.93, p<.001), as shown in Figure 5. For happy expressions, distances differed between all agents, with largest distances to congruent groups (congruent vs. single: t(755)=10.06, p<.001), followed by incongruent groups (incongruent vs. congruent: t(755)=-4.81, p<.001), followed by a single VA (single vs. incongruent: t(755)=-7.05, p<.001), shown in Figure 5.

Full Model

The full model revealed significant main effects of Constellation of VAs ($F_{2,731}$=67.86, p<.001) and of Direction ($F_{4,731}$=5.19, p<.001). Moreover, the Constellation of VA x Emotion interaction was significant ($F_{2,731}$=15.22, p<.001). The other effects did not reach significance, all Fs < 1.74, all ps > .14. Follow-up analysis of the main effect of Constellation of VA and the Constellation of VA × Emotion interaction showed comparable effects to those of the best-fitting model and are therefore not reported extensively.

Most importantly, the main effect of Direction was due to significant differences between the two peripheral directions (M_{left}=2.53,

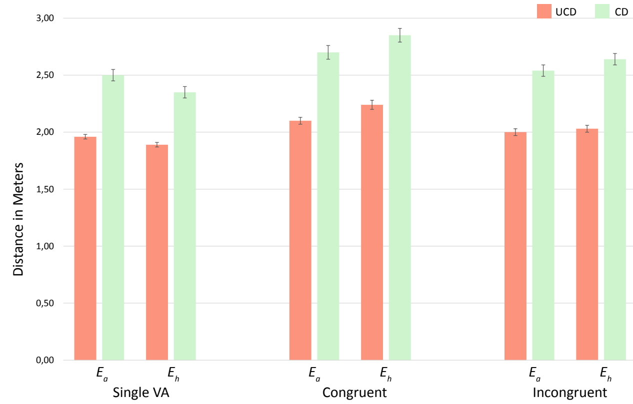

Figure 5: Means and standard errors in meters of the uncomfortable (UCD, indicated by red barrier) and comfortable (CD, indicated by green barrier) distances per treatment.

SD_{left}=.59; M_{right}=2.53, SD_{right}=.59) and the right-center direction (M=2.66, SD=.70; left vs. right-center: t(731)=-3.78, p=.002, and right vs. right-center: t(731)=-3.40, p=.007), to which the largest distance was kept. Figure 6 shows the mean distances for all directions over all treatments in green.

4.2 Uncomfortable Distance

Best-Fitting Model

In the best-fitting model, a significant main effect of Constellation of VAs ($F_{2,750}$=52.19, p<.001) and a significant Constellation of VAs × Emotion interaction were evident ($F_{2,750}$=6.40, p<.001).

As for the comfortable distance, the main effect of Constellation of VAs was driven by significant differences between all three Constellations, with largest distances kept from congruent groups (M=2.17, SD=.42, congruent vs. single: t(750)=9.57, p<.001), smallest distances to single VAs (M=1.93, SD=.23; single vs. incongruent: t(750)=-6.76, p<.001), and distances to incongruent groups in-between (M=2.01, SD=.29; incongruent vs. congruent: t(750)=-5.40, p<.001).

Decomposing the Constellation of VAs × Emotion interaction revealed effects of Emotion in the single and incongruent setup, i.e., when a single VA was approaching, larger distances were kept when the VA was angry than when he was happy (t(750)=3.76, p<.001; see Fig. 5). In the incongruent groups, the pattern was reversed, yielding larger distance to groups with a happy central than to groups with an angry central VA (t(750)=2.07, p<.001), as shown in Figure 5. In the congruent group, the difference was not significant (t(750)=0.87, p=.38).

Moreover, for angry emotions, larger distances were kept for congruent than for incongruent groups (t(750)=4.34, p<.001), and larger distances were kept to congruent groups than to a single VA (t(750)=5.19, p < .001), as shown in Figure 5. For happy expressions, distances differed between all agents, with largest distances to congruent groups (congruent vs. single: t(750)=8.22,

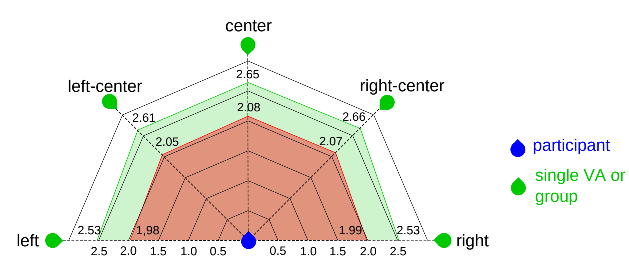

Figure 6: Mean distance in meters per direction over all six treatments.

p <.001), followed by incongruent groups (incongruent vs. congruent: $t(750)$=-3.42, p=.001), followed by single VAs (single vs. incongruent: $t(750)$=-8.52, p<.001; see Fig. 5).

Full Model

The full model revealed significant main effects of Constellation of VA ($F_{2,726}$=63.14, p<.001) and Direction ($F_{4,726}$=7.23, p<.001). Moreover, the Constellation of VA × Emotion interaction was significant ($F_{2,726}$=14.17, p<.001) and the 3-way interaction (Constellation of VA × Emotion × Direction) was also significant ($F_{8,726}$=2.29, p=.02). The other effects did not reach significance, all Fs < 3.72, all ps > .054. Follow-up analysis of the main effect of Constellation of VA and the Constellation of VA × Emotion interaction showed comparable effects to those of the best-fitting model and are therefore not reported extensively.

The main effect of Direction was due to significant differences between the two peripheral directions (M_{left}=1.98, SD_{left}=.27; M_{right}=1.99, SD_{right}=.28) and all three central directions, i.e., left-center (M=2.05, SD=.34; left vs. left-center: $t(726)$=-3.73, p=.002, and right vs. left-center: $t(726)$=-2.96, p=.019), center (M=2.08, SD=.39; left vs. center: $t(726)$=-3.4, p=.006, and right vs. center: $t(726)$=-2.9, p=.019), and right-center (M=2.07, SD=.36; left vs. right-center: $t(726)$=-3.65, p=.002, and right vs. right-center: $t(726)$=-3.01, p=.019) , revealing an elliptical shape of PS (see Fig. 6). The two peripheral extremes (left, right) did not differ significantly from each other ($t(726)$=-0.6, p=1). The three central directions also did not differ significantly from each other (center vs. left-center: $t(726)$=0.78, p=1, center vs. right-center: $t(726)$=0.4, p=1, and right-center vs. left-center: $t(726)$=0.43, p=1).

The 3-way interaction can be decomposed as follows: When a single VA was approaching, the effect of Emotion, i.e., greater distance to angry than to happy VAs, was evident only when the VA was approaching from either the center ($t(726)$=2.20, p=.028) or the two adjacent directions (left-center: $t(726)$=2.09, p=.037, right-center: $t(726)$=2.34, p=.02). This effect did not manifest when the VA was approaching from the two peripheral directions (left: $t(726)$=1.19, p=.233, right: $t(726)$=0.89, p=.37). Furthermore, when a congruent group was approaching, the effect of Emotion (which was reversed, i.e., a larger distance was kept to a happy than to an angry looking group) was evident only when the group was approaching from left-center ($t(726)$=2.63, p=.009) or right-center ($t(726)$=3.56, p<.001), and not for the other directions (left: $t(726)$=-0.53, p=.60, right: $t(726)$=-0.53, p=.60, center: $t(726)$=1.25, p=.213).

5 Discussion

Establishing PS in the CAVE, the current study investigated the effect of VAs' emotional expressions when participants were approached either by a single VA or a group of three VAs. Subjective ratings indicated high feelings of presence of both oneself and the VAs in the IVE. In a similar vein, the preferred distances to the VAs fell into the social zone of PS [17], and formed an elliptical shape. Therefore, our data run along the lines of previous research that has applied the concept of PS to VR scenarios [4,5,14]. In particular, we could show that PS perceptions and preferences in the CAVE resemble behavior in real-life situations, supporting **H1**. Building upon the opportunity of VR to maximize experimental control in interpersonal interactions, we further tested the impact of affective signals, i.e., emotional expressions.

When a single VA was approaching, participants chose larger distances to angry VAs than to happy VAs, which corroborates prior research outside virtual environments [41] and **H2**, i.e., an effect of the VA's emotion. Taking into account the different directions from which the VAs were approaching further revealed that this effect was driven by the VAs approaching from the center and the two adjacent directions. In other words, the preferred distance to an angry compared to a happy VA was maximal when the VAs were coming uncomfortably close from frontal directions, as hypothesized in **H6**.

This additional verification of PS elliptical shape also resonates with early findings of stronger negative reactions to frontal invasions of PS in males than in females (who were more sensitive to invasions from the side) [13]. Face-to-face arrangements resemble rather competitive situations and challenges than affiliative situations [13]. Such an impression is likely to be potentiated when being faced with an angry counterpart, as in the current study, which may signal threat. However, larger distances to angry VAs than to happy VAs were confined to single VAs and not observed for the two treatments in which a group of VAs was approaching.

The partial rejection of **H2**, i.e., an effect of emotion was only present for the single VA, needs to be viewed in context of the strong impact of the Constellation of VAs. As hypothesized in **H3**, groups of VAs generally evoked larger preferred distances than single VAs. In real-life walking situations, larger distances to groups as a social entity were observed and related to the size of the group [25]. By replicating these findings in VR, the current investigation makes a novel contribution to understanding and modeling behavior in groups. Considering how PS varies dependent on group size and composition is highly relevant for simulating different interactions in groups, e.g., with friends, co-workers, in sports teams, where VAs could fulfill the roles of assistants, guides or coaches.

The powerful influence of the group constellation became even more apparent when evaluating **H4** and **H5**, i.e., how congruent and incongruent emotional signals within a group of approaching VAs shape PS preferences. Being confronted with a group of multiple members that unanimously express anger can elicit feelings of rejection [19]. In a follow-up study, Heerdink et al. demonstrated that as the number of angry reactions in a majority group increases, feeling rejected by this group also increased [20]. Importantly, in contrast to dyadic interactions, groups may signal not only more of a particular emotion, but expressions may also diverge and be ambiguous with respect to the group as a social entity [20]. Consistent with these findings and with **H4**, larger distances were kept to groups unanimously showing anger, i.e., congruent groups, than to the group in which only the central VA displayed an angry expression, i.e., incongruent groups. Moreover, when VAs were coming uncomfortably close, preferences emerged for larger distances to groups with two angry VAs than to groups with only one (yet central) VA.

This linear relation between PS preferences and the number of angry expressions did not translate analogously to reactions to happy expressions. According to **H5**, we had expected larger distances to the group with one central happy, and two framing angry VAs than to the all-happy group. In contrast, the behavioral data revealed largest distances to congruent groups, followed by incongruent groups, again followed by single VAs.

Even more puzzling, yet not statistically significant, PS to all-happy groups was larger than to all-angry groups. These counter-intuitive preferences could be due to an altered perception in general, and of the unanimously happy group in particular. Notably, we did not assess participants perception of the emotions, which may limit our interpretation regarding specifically angry vs. happy expressions. Still, the PS differences we observed between angry and happy single VAs indicate that, even if not consciously perceived differently, they elicit different behavior.

Along these lines, expressions conveyed by body postures can impair the processing of facial emotions, especially when facial and bodily expressions do not match [30,33]. In the current study, the VAs bodily expression remained constant, and, without a direct measure of participants perception, one may only speculate in how far it deviated from the neutral expression we intended it to convey. However, given that the body posture was the same for all agents in all conditions, behavioral differences are likely due to the facial expressions, even if not perceived as angry or happy.

To optimize emotional expressions, future studies should be guided by assessing the perception of both facial and bodily emotions. First impressions of VAs are formed within seconds [6, 10, 11], with an agents attitude being mainly conveyed by facial expressions [10]. Although the low walking speed entailed sufficient time to form such impressions, it is likely that in our group constellation, attentional resources were divided between the three approaching VAs. With less time to visually inspect each VA, emotional signals from body posture could more easily bias group perception. Similarly, in some social interactions, a smile might not be interpreted as implying a friendly, but rather an aggressive intent. For example, a group of three smiling men approaching oneself may be perceived as threatening, with extra confidence or dominance signaled by the smile (see also Fig. 3 and [26]).

6 Conclusion

In this work, we presented a VR-based evaluation of PS preferences investigating the influence of three factors: the Constellation of VA (single VA, congruent group, incongruent group), the Emotion expressed as facial expression (angry, happy), and the Direction of approaching (left, left-center, center, right-center, right). Our results corroborate previous findings of an elliptical PS shape and provide evidence that an increasing amount of interaction partners also increases the distance kept between participants and VAs. Furthermore, they indicate that the emotion expressed by approaching VAs has an influence on the PS preferences.

Whether the results also apply to females (participants and VAs) or across gender still needs to be shown. Moreover, culture and age differences have not been taken into account in our work.

Our study is a reasonable foundation for further social and behavioral studies investigating PS preferences and aggressive behaviors. Thus, we want to investigate the influence of the emotion in more detail by adding an appropriate body language to the facial expression. Furthermore, we intend to sample the participants' PS preferences behind their backs. As the VAs from behind are not in the participant's field of view, we want to add sound to their footsteps as auditory hint for their approaching. To complement these explicit PS preferences with implicit measures of discomfort, psycho-physiological indicators like skin conductance will be assessed. For those future works, we plan to keep the culture, age and gender constant to our current study.

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