# The Impact of a Virtual Agent's Non-Verbal Emotional Expression on a User's Personal Space Preferences

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## ABSTRACT

Virtual-reality-based interactions with virtual agents (VAs) are likely subject to similar influences as human-human interactions. In either real or virtual social interactions, interactants try to maintain their personal space (PS), an ubiquitous, situative, flexible safety zone. Building upon larger PS preferences to humans and VAs with angry facial expressions, we extend the investigations to whole-body emotional expressions. In two immersive settings–HMD and CAVE–66 males were approached by an either happy, angry, or neutral male VA. Subjects preferred a larger PS to the angry VA when being able to stop him at their convenience (*Sample* task), replicating previous findings, and when being able to actively avoid him (*PassBy* task). In the latter task, we also observed larger distances in the CAVE than in the HMD.

## CCS CONCEPTS

• **Human-centered computing → Virtual Reality**; **User studies**.

## KEYWORDS

virtual agents, personal space, emotions, virtual reality

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## 1 INTRODUCTION

The discipline of social virtual reality (VR) focuses, i.a., on enhancing the behavioral design of advanced and emotional human interfaces. These are commonly represented by embodied, computer-controlled characters with a human appearance, defined as virtual agents (VAs). They function as interaction partners, i.e., as mediators of knowledge or as training partners. In order to be accepted by users, the VAs have to act and react in a human-like manner, matching the expectations raised by their anthropomorphic appearance [21]. Thus, designing VAs with a natural human behavior is a key requirement.

Observing daily social interactions suggests that managing interpersonal space is an important aspect of social behavior. To this end, our work focuses on interpersonal distance, defined as personal space (PS). It is considered to be a flexible protective zone individuals maintain around themselves [15] in real-life situations [13]. PS can be divided into four distinct zones, ranging from 'intimate' (0-45 cm), 'personal' (45-120 cm), 'social' (120-360 cm) to 'public' (>360 cm) [15]. The large ranges of each zone are due to the fact, that the distance kept is regulated dynamically while it is additionally impacted by various personal, social and environmental factors [16].

Investigating proxemic behavior of individuals is thus non-trivial. Maximal experimental control is required, while a natural frame and a direct egocentric experience allow a realistic behavior of the subjects. VR-based experiments comply with these requirements. Previous research proved that the concept of PS is applicable to VR scenarios [5] while PS preferences assessed in VR-based studies provide a high ecological validity [8, 13, 20]. Based on stop-distance paradigms often used in psychological studies [40], VAs are embedded as interactants, who either need to be approached as closely as desired [5] or who need to be stopped while approaching the subjects [8]. Building upon these works, we conducted a VR-based study, complemented with a basic desktop-based condition comparable to [40], to get further insight into human proxemic behavior.

Previous findings in Psychology indicate larger PS preferences to angry individuals [39, 40]. In a VR-based stop-distance paradigm conducted in a CAVE this finding was replicated while focusing on the frontal and lateral PS: Male subjects kept larger distances to a male VA conveying anger solely via facial expressions compared to a VA showing a happy facial expression [8]. Extending this work, we compared the impact of the *Emotions* happy, angry, and neutral, while augmenting the facial expressions by an appropriate body language. By means of the stop-distance *Sample* task, we explicitly measured the subjects' PS preferences in eight *Directions* enclosing the subjects. Consequently, footstep sound to localize the VA when being in the subjects' back was added. A subsequent *PassBy* task allowed an implicit measurement of discomfort w.r.t PS as subjects were asked to step aside if required when being closely passed by a VA. Furthermore, we investigated the impact of two *Display Systems*, namely a CAVE and a head-mounted display (HMD) without a body avatar. This initial

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comparison of displays w.r.t. PS perceptions allows us to gain a first insight on how the displays impact the users' distance perception and thus their comfort.[1] Finally, to link to common psychological studies, we added a desktop-based, third-person *Sample* task with the same stimuli as used in the VR settings, evaluating one lateral *Direction* per *Emotion*. By this, we evaluate the generalizability of the results.

The main contribution of this work is thus a deepened investigation of a user's PS adaptations in response to whole-body emotional expressions of an approaching individual. The insights gained here will enhance the VAs' human-like actions and reactions required in social VR applications by improving their proxemic behavior design.

## 2 INTERPERSONAL DISTANCE

As an essential aspect in social interactions, PS is a recurring subject of investigations. Being a non-verbal communication channel [4], human proxemic behavior, defined as the use of space in interpersonal interactions [15], reflects the nature of a relationship between an individual and its interactants. Thus, PS is considered as a personal safety zone humans try to maintain around themselves. Violations evoke discomfort [41] and physiological arousal [17], resulting in avoidant or aggressive reactions [34].

Research indicated that the exact size and shape of an individual's PS depends on numerous factors [16]. Various personal and social characteristics, such as gender, age, culture, or affective expressions [4, 20, 40] impact the PS preferences as well as environmental factors, such as lighting and in- or outdoor location [1, 12]. Often found are elliptically-shaped PS zones, with roughly twice as much space in the individual's front compared to its back and side areas [4].

Two paradigms are used for PS evaluation: *approaching* where subjects are asked to approach or pass others [5], and *stop-distance*. In the latter, subjects explicitly indicate their minimum tolerable interpersonal distance by stopping approaching interactants [8, 25].

While first PS investigations were based on real-life observations, VR-based studies are used more frequently nowadays. Research indicated that individuals also maintain their PS in immersive virtual environments [5, 18], giving validation for the VR-based settings. However, it is important to notice that the size of the PS in VR is slightly increased [13] due to distance underestimations [28]. Furthermore, research on interactions between walkers also showed that movements and gazing behaviors of individuals are comparable between VR and real-life [7, 10]. Hence, VR-based experiments proved themselves to provide a valid assessment of the physical PS preferences [8, 20].

In VR-based studies, subjects, e.g., move away from approaching VAs to maintain their PS [5] and respect the PS of VAs when approaching or bypassing them [31], while being influenced by the number and formation of the VAs [8, 9] or the VAs' gazing behavior [5, 11, 22]. Furthermore, realistic motions and physical appearances have a great influence on the subjects' comfort, while subjects respond negatively to eerie and less human-like appearances of the VAs [30, 42].

In addition, subjects keep a larger distance to VAs with angry facial expressions compared to those with happy ones [8]. This substantiates findings of real-live observations [39] and desktop-based studies [40]. This finding implicitly demonstrates that subjects are able to perceive emotions expressed by VAs through their facial expressions. The same is true for gait and by this for full-body motions [27, 36]: When walking together with an expressive VA, users, e.g., adapt their own locomotion w.r.t. the VA's emotion while maintaining a qualitatively similar PS compared to real-life [32].


happy $E_h$ angry $E_a$ neutral $E_n$

**Figure 1: Facial expressions and stills of the used animations.**

However, to the best of our knowledge, no systematic approach was yet used to explore the impact of whole-body emotional expressions of an approaching or bypassing VA on a user's PS preferences. Thus, we address this gap with our study.

## 3 VISUAL & ACOUSTIC STIMULI

Previous research already found an influence of different facial expressions on a user's PS preferences [8]. However, as psychological studies question the reliability of emotions perceived only from facial expressions [37], more channels should be used when designing expressive VAs. Besides the facial expressions, these *expressive features* [35] can be body postures, gazing behaviors, and movements [6, 33]. The latter option comprises gait [33] and the trajectories chosen. As our study requires specific trajectories to sample the subjects' PS preferences, we focus on the body-language.

The *Emotions* tested are happiness ($E_h$), anger ($E_a$), and neutrality ($E_n$). As they are apparent during walking and persist for a longer period of time [26], they are well suited for our study tasks.

We used SmartBody's male character Brad [38] as VA. For the gazing, a basic model was used, including blinks to avoid uncomfortable staring. As direct gaze is associated with approach-oriented emotions (i.e., $E_h$ and $E_a$) [2], the VA engages in mutual gaze while approaching and bypassing the subject. After passing the subject, he looks straight ahead. This gazing model was reused for $E_n$, to keep the gazing channel consistent.

To define suitable facial expressions via the facial action units (see Fig. 1, upper row), we referred to the extensive literature (e.g., [24]). Although bodily emotional expressions are not yet being researched in depth, it is known that matching postures improve recognizing facial expressions [23]. Thus, we used a more sophisticated approach to select an appropriate animation per *Emotion*.

For the body postures and gaits *Animation Datasets* (*ADs*) from Adobe's Mixamo[2] were used. The emotional expressions resulting

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[1] As stated later, a systematic evaluation (i.a., HMD with body avatar) has to follow.

[2] https://www.mixamo.com/; last-visited: 2020-09-13

from combining all channels (pre-defined gaze and facial expression, variable *ADs*) were carefully validated in a perception study, detailed in the supplemental material[3]. The best-fitting animations per *Emotion* (see Fig. 1, lower row) were then used in the main study.

To allow localizing the VA when being out of sight, footstep sound is required. While walking in an anechoic chamber, an actor reenacted the Emotions $E_h$, $E_n$, and $E_a$, varying his steps from fleet-footed over a neutral gait to stomping. In a post-processing, the recorded steps were then matched with the visual steps of the animations.

## 4 STUDY ON PERSONAL SPACE PREFERENCES

After selecting our stimuli, we investigated the influence of our VA's whole-body emotional expressions on subjects' PS preferences in a within-subjects user study. As gender and age influence PS [4], we restricted the participation to German males in the age range of 18 to 30 years. They had to conduct two tasks allowing us to first assess their PS preferences directly (*Sample*) and afterwards indirectly by means of a linked behavioral measurement (*PassBy*). *Sample* was conducted with the three *Display Systems* desktop, HMD, and CAVE. For the succeeding *PassBy*, only the immersive displays were used.

### 4.1 Hypotheses

We expected the following hypotheses to be confirmed:

H1 *The subjects' PS preferences are within Hall's social zone.*
The social zone is known for interactions among strangers [15], as which the approaching VA will be perceived due to missing direct interactions during the repeated encounters. Thus, we expect the subjects to keep the VA in this zone.

H2 *Subjects show elliptically-shaped PS preferences.*
We expect our findings to be in line with the literature [4, 8].

H3 *Subjects keep a larger distance to the VA expressing anger compared to the one expressing happiness.*
We expected to extend the findings of [8, 40] on larger PS preferences to VAs with angry facial expressions than to VAs with happy ones to matching bodily emotional expressions.

H4 *Subjects keep smaller distances to the approaching VA if allowed to move away compared to standing still.*
PS is functioning as a protective zone. Which safety clearance is perceived as suitable is thereby highly situation-dependent. When subjects are allowed to step aside on feeling uncomfortable, they can easily readjust the PS if required. Thus, we expect smaller safety clearances to be chosen compared to situations in which subjects cannot avoid the VA actively.

H5 *The subjects' PS preferences are larger in the HMD conditions compared to the CAVE conditions.*
In the expected PS preference range of $120 - 360cm$ ($H1$), distances are often underestimated in HMDs while more precisely estimated in CAVEs [14]. Therefore, we expect participants to stop the VA earlier, resulting in larger PS preferences in the HMD condition.

### 4.2 Tasks

Our study consists of two subsequent tasks, namely:

**Figure 2: Desktop-based stop-distance paradigm: Users drag the stimuli via a mouse towards their own representation.**

Sample *Task.* This task is an explicit assessment of the subject's PS preferences based on the stop-distance paradigm used in experimental psychology studies. It was conducted in two fashions.

First, a classic desktop-based version replicating the setting of [40] was used to assess the lateral PS preferences for a relative comparison between the *Emotions*. As shown in Figure 2, the subject saw his own virtual representation and dragged a virtual space invader via mouse-control towards it. All three invaders are stills of the stimuli selected in the perception study (see Fig. 1).

Second, we used a computerized version of the classic real-life stop-distance paradigm for both VR settings. Here, the subject was positioned in the middle of our scene, looking straight ahead. Per *Emotion*, the VA approached him directly from eight directions, as shown in Figure 3, in a randomized order. The subject was asked to press a designated button on the input device anytime during the VA's approach when feeling uncomfortable due to the interpersonal distance. Thus, the minimum tolerable distance was assessed, equivalent to the uncomfortable distances collected in [8]. Triggered by the button press, the VA stopped, faded out, and was initialized again at the start point of another direction. During this complete process, the subject was instructed to remain on his position and only look around by upper-body movements. Footstep sounds via binaural audio were used to allow the localization of the VA. This was particularly important to draw the subject's attention to the events in his back. Here, subsequent observations revealed, that the footsteps were used as main indicator of proxemics. When subjects had an impression of a close spatial distance, they looked back and pressed the button.

PassBy *Task.* This task is a behavioral measurement of the PS preferences and an implicit evaluation of the PS data collected in the *Sample* task. As there is no meaningful side view equivalent for the desktop, this task was only conducted in both immersive settings.

We are interested in the interpersonal distance established by the subject's avoidance movements. To this end, the subject is initially

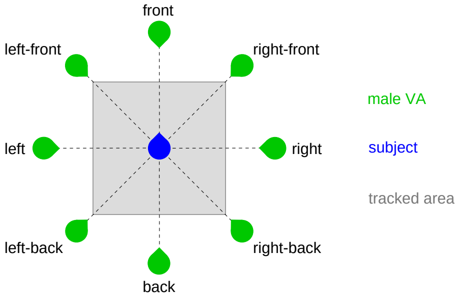

**Figure 3: Eight *Directions* from which the VA approached the subject in a randomized order. (Fig. adapted from [8]).**

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[3] PDF: https://doi.org/10.18154/RWTH-2020-09106
Video: https://youtu.be/w6bjWO1G_tw

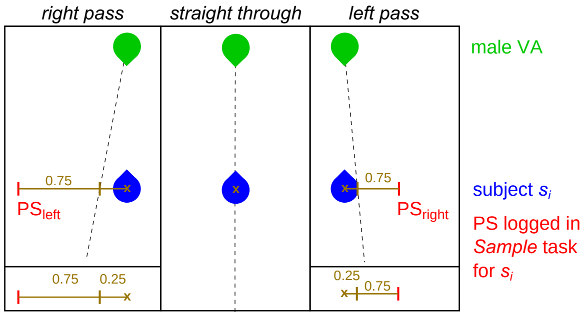

**Figure 4: Distance-based computation of new trajectory per *Violation* for *PassBy* shown for *Direction front*.**

located in the scene's middle and allowed to move aside when feeling uncomfortable due to the proxemics. The VA passes by closely, consciously invading the safety clearance defined by the respective subject in the *Sample* task and sometimes even fostering a collision.

The starting points of the VA's trajectories are the same as those for the previously used directions *left*, *left-front*, *front*, *right-front*, and *right*. Their exact directions are then individualized per subject $s_i$. We generate three straight paths per start point, introducing three levels of *Violation* (cp. Fig. 4) by passing through ...

*right pass*: ... a point located 25% towards the PS preference of $s_i$ stored for the second next *Direction* counter-clockwise,

*straight through*: ... the location of $s_i$ itself, and

*left pass*: ...a point located 25% towards the PS preference of $s_i$ stored for the second next *Direction* clockwise.

Thus, in total 15 individualized trajectories per *Emotion* were tested. By taking into account PS preferences stored for the second counter- as well as clockwise direction, we ensured that the complete PS zone is evaluated while focusing on the frontal area. Taking 0.25 of the initially gathered distance preference ensured a near collision and thus we forced the subject to react and move aside.

### 4.3 Virtual Environments

To rule out a negative influence of environmental factors while measuring the emotions' impact, we chose two basic environments: In the desktop-setting, we used a uniform, light gray background (see Fig. 2). In the immersive settings, we used an empty, large-scale outdoor courtyard with a bright illumination (see supplemental material).

### 4.4 Equipment

Three *Display Systems* have been used in our study.

$DS_{desktop}$ is a Lenovo ThinkPad $T450s$ Ultrabook (14" screen) and a wired optical mouse (Dell, model $570-11147$) for interaction.

$DS_{HMD}$ is an HTC VIVE Pro, tracked at $90Hz$ by means of two tripod-mounted SteamVR Base Stations 2.0 in an area of $4.80m \times 4.80m$ ($w \times d$). One Vive controller was used for interaction, while the build-in headphones played the binaural audio.

$DS_{CAVE}$ is a five-sided CAVE with a size of $5.25m \times 5.25m \times 3.30m$ ($w \times d \times h$). Subjects wore active stereo glasses tracked at $60Hz$ and used an ART Flystick 2 for interaction. The five screens provide a 360° horizontal field of regard, while the CAVE's ceiling is equipped with an advanced acoustic system. By means of two separate virtual sound sources next to the subjects' ears using crosstalk cancellation, we generated the binaural audio. Via two security cameras, the supervisor was able to unnoticeably observe the fully immersed subject.

### 4.5 Experimental Design

We chose a within-subjects design with three independent variables: (a) the *Emotions* $E_h$, $E_a$, and $E_n$ expressed by the VA, (b) the eight *Directions* from which the VA approached, and (c) the *Display System* ($DS_{desktop}$, $DS_{HMD}$, and $DS_{CAVE}$) used. For both tasks *Emotion* resulted in three treatments. For the *Sample* task, the *Direction* caused eight runs per treatment on $DS_{HMD}$ and $DS_{CAVE}$ and well as one run on $DS_{desktop}$. For the *PassBy* task, the *Direction* caused 15 runs per treatment on $DS_{HMD}$ and $DS_{CAVE}$.

### 4.6 Procedure and Data Collection

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

On arrival, subjects were informed about the procedure, gave their informed consent and filled out a demographic questionnaire. Then, they conducted both immersive settings in a randomized order. $DS_{desktop}$, allowing comparability to studies like [40], has the least significance for our research interest and was thus conducted last. Finally, subjects received 15€ compensation and left. In total, the study took about 70 min/subject, from which 45 were spent fully immersed.

The procedures at $DS_{HMD}$ and $DS_{CAVE}$ were identical. After being introduced to the safety regulations, subjects were immersed in the empty study scene. When feeling comfortable in the VR environment, a familiarization phase started. Here, subjects learned handling the input device by conducting the *Sample* task with a neutral female agent approaching them from three directions. Then the official study part began with the male VA. Subjects had to conduct the treatments $E_h$, $E_a$, and $E_n$ of the *Sample* task in a randomized order. After all three *Sample* tasks, a virtual text box informed the subjects that they were about to start the *PassBy* task and that they were now allowed to move. Subjects confirmed the note and conducted the treatments $E_h$, $E_a$, and $E_n$ of the *PassBy* task in a randomized order. To be able to evaluate the avoidance movement, subjects had to return to their initial position after the VA passed to start the next passby from another direction. After one treatment was done, the next started directly. Afterwards, subjects took a short break, followed by the next study part at another *DS*.

We logged the subjects' and the stimuli's (VA or virtual space invader) position and orientation as well as the Euclidean Distance between both continuously throughout the study.

### 4.7 Subjects

Among others, PS is impacted by various personal and cultural factors [16]. To thus keep the results comparable, we limited participation to German males aged from 18 to 30 years.

We recruited 66 males (age: $M$=23.3, $SD$=2.99) via announcements at notice boards in our university. All had (corrected-to) normal vision and normal motor skills. Eighteen used a VR display before.

## 5 RESULTS

Statistical analysis was performed using SPSS 25.0. The significance threshold of $\alpha = .05$ was corrected by dividing the level by the number of analyzes (5). Consequently, all main effects or interactions with a $p$-value less than .01 were considered significant. Similarly, all pairwise comparisons were Bonferroni-corrected. Only significant effects, i.e., main effects, interactions and follow-up comparisons, are reported. In addition, the means, standard deviations, and standard errors for the distance at the $DS_{HMD}$ and $DS_{CAVE}$ are given in meters.

## 5.1 Sample Task

*Desktop Sampling.* The data were not normally distributed and therefore compared by means of non-parametric tests, i.e., the Friedman Test with Wilcoxon Signed Ranks Tests for follow-up comparisons. The Friedman Test showed a significant difference between the emotional expressions ($\chi^2 = 91.76, p < .001$). The non-parametric post-hoc tests indicated significant differences between all three emotions (all $ps < .001$). Larger distances were kept when the VA was angry, followed by happy and then neutral (see Fig. 5).

*Immersive Sampling.* PS was indexed via the Euclidean Distance from the position of the VA to the position of the subject when he pressed the button. There were no missing values. As the data were (mostly) normally distributed, repeated measures ANOVAs with the within-subject factors *Display System* ($DS_{HMD}$, $DS_{CAVE}$), *Emotion* ($E_h$, $E_a$, $E_n$), and *Direction* (*left*, *left-front*, *front*, *right-front*, *right*, *right-back*, *back*, *left-back*) were conducted.

The *Display System* × *Emotion* × *Direction* ANOVA showed significant main effects of *Emotion* ($F_{2,130}$=30.32, $p$<.001, partial $\eta^2 = .32$), and a significant main effect of *Direction* ($F_{7,455}$=6.74, $p$<.001, partial $\eta^2 = .09$), as well as a trend for an *Emotion* × *Direction* interaction ($F_{14,910}$=2.09, $p$=.082, partial $\eta^2 = .03$). No other effects were significant (all $Fs < 1.45$, $ps > .22$).

The main effect of *Emotion* was due to larger distances to angry VAs ($M$=1.82, $SD$=.83) than to happy ($M$=1.64, $SD$=.68) and neutral VAs ($M$=1.53, $SD$=.63) with all $ps < .001$.

The main effect of *Direction* was due to significant differences between the *right-back* and *back* directions compared to the frontal directions of *left*, *left-front*, *front* and *right-front* (all $ps < .033$). Descriptively, the three top directions, i.e., *left-front*, *front* and *right-front*, yielded the largest distances, as shown in Figure 6.

## 5.2 PassBy Task

The minimal Euclidean Distance between the VA and the subject during each run was used as an index for PS. Due to a program error w.r.t to the computation of the *Violation* trajectories discovered after the study, we have missing values as well as repeated measurements for some subjects. Ignoring the latter, 41% of the values (27 out of 66) are missing on average for *right pass* and 35% for *left pass*. However, taking the repeated measurements into account, we still have on average 45 or more values per *Violation* and *Emotion* ($avg_{right\ pass}$: 45, $avg_{straight\ through}$: 101, $avg_{left\ pass}$: 52). As these figures are computed while averaging over *Emotion*, *Direction*, and *DisplaySystem*, we concluded that sufficient data was gathered for a prudent analysis of the *PassBy* task. To this end, a generalized linear mixed model with normal distribution and identity link function was applied for the PS as the dependent variable. The data was structured as nested in *Display Systems* ($DS_{HMD}$, $DS_{CAVE}$), *Emotion* ($E_h$, $E_a$, $E_n$), *Direction* (*left*, *left-front*, *front*, *right-front*, *right*), and *Violation* (*right pass*, *straight through*, *left pass*). We included all factors and all interactions as fixed effects, while the subjects were modeled as random effects. In addition to this full model, reduced models were computed. By means of the corrected Akaike Information Criteria (AIC) [3] we estimated the quality of the resulting set of statistical models in relation to each other. The best-fitting model (smallest AIC), which ensures that the model neither under- nor over-fits, was chosen for report.

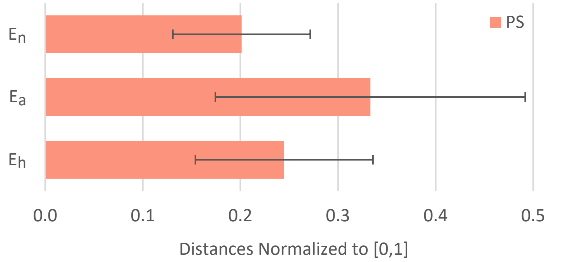

**Figure 5: Means normalized to [0,1] and standard deviations of the subjects' PS preferences per *Emotion* for $DS_{desktop}$.**

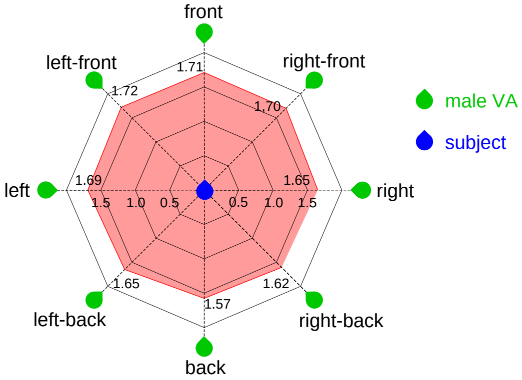

**Figure 6: Mean distance in meters per *Direction* over all *Emotions* and immersive *Display Systems* (adapted from [8]).**

*Best-Fitting Model.* Our best-fitting model contains five factors, i.e., the *Display Systems*, the *Emotion*, the *Violation* and the interactions between *Emotion* × *Violation* and *Display Systems* × *Emotion*. They all revealed a significant effect on the PS.

The main effect of *Display Systems* was due to larger distances in the $DS_{CAVE}$ ($M$=.989, $SD$=.386) than with the $DS_{HMD}$ ($M$=.91, $SD$=.342) with $F_{1,5.928}$=251.139, $p$<.001.

The main effect of *Emotion* ($F_{2,5.928}$=226.405, $p$<.001) was due to larger distances to angry VAs ($M$=1.038, $SD$=.411) than to happy ($M$=.916, $SD$=.334) and neutral VAs ($M$=.894, $SD$=.333), all $ps < .001$.

The main effect of *Violation* ($F_{2,5.928}$=268.526, $p$<.001) was due to smaller distances when the VA passed straight through the subjects ($M$=.901, $SD$=.346) than when passing by either left ($M$=1.003, $SD$=.382) or right ($M$=.995, $SD$=.381) with all $ps < .001$.

The *Emotion* × *Violation* interaction ($F_{4,5.928}$=7.140, $p$<.001) was evident as an effect of *Emotion* for all three violation levels (with largest distances to angry VAs, followed by happy and neutral) except for neutral VAs comparing the distance for left and right pass ($p$=.742). Furthermore, an effect of *Violation* was evident for all three emotions (with smallest distances when the VA was passing *straight* *through*, followed by right and left pass), except for right pass ($p$=.921) and straight through ($p$=.057) comparing happy and neutral VAs.

Similarly, the *Display Systems* × *Emotion* interaction ($F_{2,5.928}$= 11.156, $p$<.001) was evident as an effect of *Display System* for all three emotions (with largest distances in CAVE conditions compared to HMD) except in the HMD condition comparing happy and neutral VAs ($p$=.348), and as an effect of *Emotion* for both display systems (with largest distances to angry VAs, followed by happy and neutral).

*Full Model.* The full model revealed significant main effects for *Display Systems* ($F_{1,5.850}$=173.731, $p$<.001), *Emotion* ($F_{2,5.850}$=2177.386, $p$<.001), *Direction* ($F_{4,5.850}$=3.698, $p$=.005), and *Violation*($F_{2,5.850}$= 238.753, $p$<.001). Moreover, the interactions *Emotion* × *Violation* ($F_{4,5.850}$=5.844, $p$<.001) and *Display Systems* × *Emotion* ($F_{2,5.850}$=8.894, $p$<.001) were significant. The other effects did not reach significance, all $ps > .205$. Follow-up analysis of the main effect *Display Systems*, *Emotion* and *Violation* as well as of the two interactions showed comparable effects to those of the best-fitting model and are therefore not reported extensively. The main effect of *Direction* was due to a significant difference ($p$=.002) between the two directions *right-front* ($M$=.972, $SD$=.383) and *right* ($M$=.933, $SD$=.35). All other comparisons were not significant, all $ps > .118$.

## 5.3 Task Comparison

To compare *Sample* and *PassBy* PS preferences, PS data from the five directions of both tasks (for *PassBy* the *Violation* level *straight through* was used) were subjected to a repeated measures ANOVA with the within-subject factors *Display Systems* ($DS_{HMD}$, $DS_{CAVE}$), *Task* (*Sample*, *PassBy*), *Emotion* ($E_h$, $E_a$, $E_n$) and *Direction* (*left*, *left-front*, *front*, *right-front*, *right*)).

For the sample data, the *Display Systems* × *Task* × *Emotion* × *Direction* ANOVA showed significant main effects of *Task* ($F_{1,65}$=104.32, $p$<.001, partial $\eta^2 = .62$), of *Emotion* ($F_{2,130}$=42.75, $p$<.001, partial $\eta^2 = .32$), and of *Direction* ($F_{4,260}$=4.8, $p$=.002, partial $\eta^2 = .07$). Moreover, there were significant interactions of *Display Systems* × *Task* ($F_{1,65}$=8.05, $p$=.006, partial $\eta^2 = .11$), of *Task* × *Emotion* ($F_{2,130}$=18.01, $p$<.001, partial $\eta^2 = .22$), and of *Display Systems* × *Emotion* × *Direction* ($F_{8,520}$=2.84, $p$=.009, partial $\eta^2 = .04$). All other effects were not significant (all $Fs < 1.75$, $ps > .15$).

The main effect of *Task* was due to larger distances in the *Sample* ($M$=1.69, $SD$=.7) than in the *PassBy* ($M$=.90, $SD$=.3) task.

The main effect of *Emotion* was due to larger distances to angry VAs ($M$=1.42, $SD$=.52) than to happy ($M$=1.27, $SD$=.43) and neutral VAs ($M$=1.19, $SD$=.40) with all $ps < .001$.

The main effect of *Direction* was due to smaller distances when the VA was approaching from the *right* ($M$=1.27, $SD$=.43) than when he was approaching from the *left-front* ($M$=1.32, $SD$=.45, $p$=.01), *front* ($M$=1.32, $SD$=.46, $p$=.021) or *right-front* ($M$=1.33, $SD$=.46, $p$<.001).

The *Display Systems* × *Task* interaction resulted from a significant effect of *Display Systems* for the *PassBy* task ($F_{1,65}$=22.08, $p$<.001, partial $\eta^2 = .25$), but not the *Sample* task ($F_{1,65}$=.64, $p$=.431, partial $\eta^2 = .01$), with larger distances in the $DS_{CAVE}$ than in the $DS_{HMD}$.

The *Task* × *Emotion* interaction was due to significantly larger distances to happy than neutral VAs in the *Sample* task ($p$<.001).

The *Display Systems* × *Emotion* × *Direction* interaction can be decomposed as follows: For angry VAs approaching from the *left* and *right* directions, larger distances were evident in the $DS_{CAVE}$ than with the $DS_{HMD}$ ($p$=.028). While there were no significant effects for happy VAs, or neutral VAs, larger distances were kept in the $DS_{CAVE}$ than with the $DS_{HMD}$ when he was approaching from the *left-front* ($p$=.009). Moreover, in the $DS_{CAVE}$, distances differed between VAs emotional expression at all directions (all $ps < .026$) except for happy and neutral VAs when approaching from the *left* ($p$=1). In the $DS_{HMD}$, there was a similar pattern of significant differences depending on the emotional expression for all directions (all $ps < .043$), but distances between happy and neutral VAs did not differ when approaching from the *front* and *right-front* (all $ps > .11$), and distances to angry and happy VAs did not differ when they were coming from the *right* ($p$=.059). Furthermore, in the $DS_{CAVE}$ for neutral VAs, distances differed between *front* and the *right* direction ($p$=.008). In the $DS_{HMD}$, for angry VAs, distances differed between the *right* and the *left-front*, *front* and *right-front* directions (all $ps < .038$).

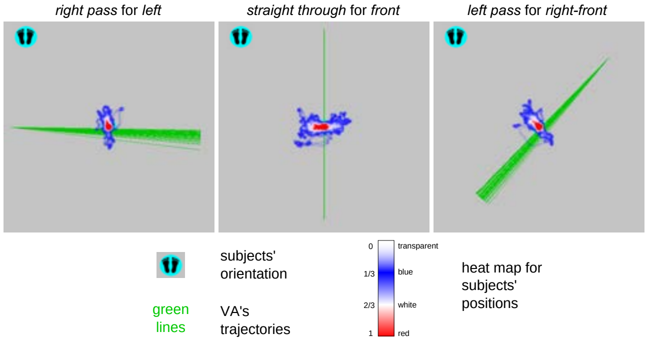

**Figure 7: Subjects' avoidance movements during *PassBy* for the individualized trajectories of the happy VA in $DS_{CAVE}$.**

## 6 DISCUSSION & IMPLICATIONS

Our study focused on the impact of whole-body emotional expressions of an approaching male VA on subjects' PS preferences. To this end, the VA expressed either happiness, anger or no emotion via four expressive features: gazing, facial expression, body posture, and gait.

Our version of the desktop-based stop-distance paradigm commonly used in psychological studies [40] showed an impact of the emotional expressions on the proxemics. Moreover, the gathered data correlated with the interpersonal distances sampled in both immersive settings, further substantiating VR-based evaluations.

Replicating findings of [40] and [8], larger interpersonal distances were maintained towards the angry VA, compared to the other ones. This supports **H3**. Interestingly however, subjects kept larger distances towards the happy VA than to the neutral one, contradicting [40]. While the animation of $E_n$ consists of subtle and minimal motions, the happy VA takes up more space due to excessive, far sweeping movements with both arms (cf. limitations and supplemental material). This likely rises the need for a larger safety clearance.

PS preferences collected in the *Sample* task reveal that the VAs are kept in the social zone, supporting **H1**. Furthermore, larger distances were found for the three frontal *Directions*. Thus, the preferred PS forms an elliptical shape[4], supporting **H2**, albeit not as distinct as in [4] in terms of the ratio of the ellipses' principal axes. Due to

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[4] See the supplemental material for a minor discussion on a recent finding of close-to-circular shapes of PS.

an additionally large distance preference for the left *Direction*, the ellipse is slightly rotated. This can be explained by the link between the lateral PS and the handedness [19]. For right-handed individuals, the need for a larger PS to the left is to be expected [13]. With 60 of our 66 subjects being right-handed, our findings thus match the expectations. In addition, subjects accepted lower interpersonal distances in the *PassBy* task when the VA approached from the right, i.e., their dominant side.

The data collected in the *PassBy* task revealed larger PS preferences in the CAVE compared to the HMD, while for the *Sample* task no difference w.r.t. the *Display Systems* could be found. These findings contradict **H5**. Interpreting our results, two assumptions arise. (1) We observed that all subjects in both scenarios stood up straight with both arms and hands at their sides during the *Sample* task and only rotated their head and upper body to look at the approaching VA. As they remained almost static, the key reference frame for proxemic behavior might have shifted from their own body (as initially expected) to the movement of the VA in the scenery. Therefore, the *Display System* used does not have any impact on PS preferences of a static user. (2) In contrast, the *Display System* has an influence on the PS preferences of an active, i.e., moving user. For HMD-based collision avoidance tasks, Mousas et al. found that a body avatar as permanent reference frame leads to longer walking routes of the subjects compared to the avatar's absence [31]. They concluded that the avatar raises the subjects awareness of the environment and thus the danger of a potential collision. Transferring this conclusion to our scenario implies that the subjects were more aware of the distance between themselves and the VA in the CAVE, as they could see their own body, leading to larger avoidance movements. In the HMD however, the subjects' body reference was missing, so smaller PS preferences were found.

Descriptively, the mean PS preferences in the *PassBy* task are within the outer range of the personal zone, thus partially contradicting **H1**. However, this finding clearly supports **H4** as actively moving subjects kept smaller distances from the VA compared to static ones. In dynamic scenarios, subjects are thus comfortable with a smaller safety zone as they can actively avoid the interactant at any time by moving further aside–at least in empty scenes as ours.

Taking the three tested *Violation* levels of the *PassBy* task, in which subjects knew about the risk of colliding with the VA, into account adds a new dimension to the aforementioned finding. Smaller differences were kept when the VA passed straight through the subjects, compared to passing by either left or right. For all three violation levels, Figure 7 illustrates the different VA paths caused by the individualized trajectory computation introduced in Section 4.2 as well as examples of resulting avoidance movements. Observations show that some subjects turned towards the VA watching him pass by, some remained sidewise or with their backs to the VA. Furthermore, subjects started their avoidance movement shortly after the VA started approaching them. Thus, we assume that the interpersonal distance difference is caused by the different identifiabilities of the VA's exact trajectories. Given that the path for *straight through* unequivocally goes straight towards the subjects, they can easily identify which safety clearance they will need in order to maintain their personal space or at least avoid a collision. For the other two trajectories, the exact paths are not as clear. Due to the angle between the straight reference axis and the VA's actual path, foreseeing the exact distances between the subjects and the VA during the ongoing approach is hampered. Thus, subjects may try to cope with this uncertainty by larger avoidance movements.

Despite the valuable study results, we need to address a **limitation** already mentioned beforehand: Adobe's Mixamo only provides a narrow set of animations and focuses primarily on the entertainment sector in contrast to serious research as, e.g., behavioral studies. Thus, besides only having a limited choice regarding the three target emotions, several animation datasets were also exaggerated. For our perception study (see supplemental material) we already chose the most natural ones, however, more advanced and diverse animations representing our target emotions would improve the insights gained.

After overcoming the animation shortcoming, there are several avenues for **future work**: As there are various influencing factors on PS preferences, e.g., gender [20], we intentionally narrowed down the subject group to German males to achieve a good comparability of the gathered data. This allowed us, to validate our setting. However, in the next steps more variety has to be taken into account, by including female subjects as well as a female VA for the treatments. Combined with a larger, more natural set of motions, more insight can be gained, e.g., deepening research on motion cues, gender, and attractiveness in the regulation of proxemics (e.g., [43]). Furthermore, more insight into HMD settings is desirable, evaluating the influence of a body avatar on the PS preferences. Here, research indicating the benefit of a permanent reference in form on an embedded, correctly animated body avatar for a precise distance estimation [29] or for raising the subjects awareness of the environment has to be taken into account.

We carefully designed a homogenous experimental setup to minimize the impact of external factors. Although the restricted animations as well as the narrowed sample demography limit the generalization of or result, a systematic analysis of the interaction of a VA's emotional expressions, the level of dynamics in the scenario, and the display system, yielded the following **implications** for the social VR research: (1) Supporting findings presented in [7], both immersive displays are suitable devices for studies on walking behavior. However, in dynamic HMD scenarios, the presence of a body avatar should be carefully considered (cf. [31]). (2) Proxemic behavior of VAs designed for CAVE environments can be used in HMD settings as well. Using an HMD-application in a CAVE, however, requires updating the interpersonal distance regulations - at least if users are able to actively move around. (3) As VR-based interactions with VAs are likely subject to similar influences as human-human interactions, the insight from our study can enhance the proxemic behavior design of VAs. It turned out, that the design of VAs w.r.t. proxemic behavior does not only depend on individual features of the VA or the user, or on the spatial constellation between both, but also on situational factors in the interaction itself. For static user-agent interactions, Hall's PS zones provide appropriate interpersonal ranges, confirming previous studies. For dynamic walking scenarios, interpersonal distances can be shrunken compared to static scenarios. If the VAs' trajectories are clearly identifiable, the shrinking factor can be larger compared to partially unforeseeable paths. With this finding we expand the insights gained in [32], who solely focused on joint walking with an expressive VA. However, the homogenous setup and sample of our study limit its generalizability. Future research needs to broaden our insights by investigating different gender, age, or cultural groups. Drawing on specific, absolute values per sample demography will be beneficial for the design of VAs' proxemic behavior for targeted applications.

## 7 CONCLUSION

We presented the results of a VR-based study, analyzing the impact of whole-body emotional expressions of an approaching male VA on subjects' PS preferences. Four factors were subject of investigation: the *Emotion* expressed via body-language, the *Direction* of approaching, the *Display System* used, and the *Task* to be conducted.

Our results replicate previous findings of a PS with an elliptical shape and thus the impact of the *Direction* of approach. Furthermore, we showed that the *emotional expressions* have indeed an influence on the PS preferences: subjects kept larger interpersonal distances to the angry VA compared to the happy and neutral one. This could be shown for situations in which subjects could stop the VA at their convenience (*Sample* task) as well as for situations in which subjects could actively avoid the VA by moving aside (*PassBy* task). Additionally, we observed larger avoidance movements during the *PassBy* task in a CAVE compared to an HMD without a body avatar.

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