Give me some room please! Personal space bubbles for safety and performance

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Abstract

Personal space bubbles are implemented in virtual environments to protect users from physical harassment. When activated, an impermeable boundary encloses the user completely and complicates collaborative tasks, such as passing objects or performing social gestures. When personal space protection is not balanced with functionality, the personal space bubble becomes a gilded cage. In this paper, we raise the possibility of alternate designs for personal space bubbles and test their impact on task performance within a workplace training context. Our early findings suggest that alternate bubble designs have the potential to balance safety and performance metrics such as task completion.

Keywords: Privacy, personal space bubbles, design, user study evaluation.

Index Terms: K.6.1 [Management of Computing and Information Systems]: Project and People Management—Life Cycle; K.7.m [The Computing Profession]: Miscellaneous—Ethics

1 Introduction

Physical harassment in virtual environments is a growing concern that personal space bubbles seek to address. The most straightforward design is a radius around the user's avatar that is impermeable to others. This implementation has been approved by researchers and users as an elegant solution [2,5]. The problem is that when the bubble is activated, it encloses the user completely and complicates collaboration in virtual experiences. If safety is not balanced with utility, users may turn off the bubble in order to participate in a virtual experience more fully. Virtual spaces are being incorporated into the workplace, a situation where users may feel they have no choice if they want to earn their livelihood. We examine personal space bubble design motivated by the goal of balancing the safety-utility tradeoff: what type of bubble design will allow a user to feel safe while also completing a collaborative task?

Boundaries to protect personal space have been explored in terms of their size and behavior [5], but were constrained to the standard cylindrical bubble parameterized by its radius. However, the problem of personal space in virtual environments is more complex than an isotropic radius [1], and should consider utility and embodiment [7]. Our work is the first to examine alternative bubble designs.

2 Method

Bubble creation Bubbles were implemented in Unity as passive informational bubbles. When an avatar's physical body invades another avatar's bubble, the bubble changes from a translucent white to a semi-translucent red color to indicate that personal space has been breached. The bubbles do not block or repel avatars.

We implement three bubble shapes (Figure 1). To make the bubbles comparable in size, the distance from the avatar's root bone (hips) and the bubble's furthest point when projected down to the

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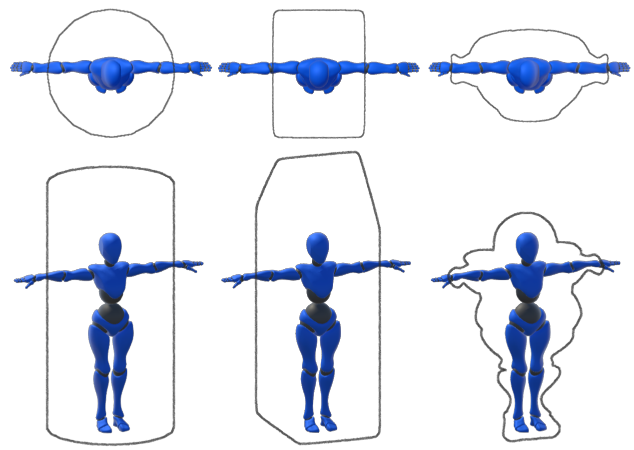

Figure 1: Full view and top-down view angles with outlines showing bubble shapes and sizes. From left to right: cylindrical, polygonal, body shape.

XZ plane is 0.5 meters. Each condition is constrained to a 1 meter diameter at the largest XZ cross-section. The bubble types are:

1. **Cylinder:** A cylinder of $D = 1$m anchored on the root bone spans over the avatar's full height. This isotropic bubble shape is the de-facto bubble available in VR worlds today.
2. **Polygon:** A pentagonal prism with a rectangular base anchored on the root bone spans the avatar's full height. The forward-axis length $L = 1$m, while the side-axis width $W = 0.725$m. Narrow sides enable avatars to stand side-by-side.
3. **Body Shape:** This bubble design conforms to the avatar's geometry. This bubble was implemented by scaling copies of the sub-meshes of the avatar by a factor of 2.85, excluding the hands. The scaled torso component's width at the shoulders is equal to $W = 1$m. Every sub-mesh is anchored to the corresponding joint of the animation skeleton, allowing the bubble to follow the avatar's movements unlike the other designs.

Protocol As gender affects proxemics [3] and the experimenter steering the second avatar is female, we limit our study to female participants and use female robot avatars. An acclimation task is followed by a set of collaborative tasks and survey conducted within the virtual environment. The collaborative tasks and survey are repeated for each condition (cylindrical, polygonal, and body shape) in a random order. Participants used an Oculus Rift to control an embodied avatar, while the experimenter controlled another avatar using a keyboard and mouse. Interactions, including high-fives and hand-offs, were performed by the experimenter using set animations.

Acclimation tasks The experimenter instructs the participant on how to grab sandwich ingredients off of tables using controller button presses and then to create three sandwiches. This task is timed and familiarizes the participant before performing the task in the collaborative environment to reduce ordering effects.

The next task establishes baselines on participants' proxemic comfort in the virtual environment. The participant is repeatedly asked to close their eyes before another avatar appears at 2m, 1m, and then 0.5m distance. The experimenter instructs the participant to open their eyes and rank their discomfort verbally. The participant

Figure 2: Collaborative task environment.

Distance	Mean	SD
0.5m	5.159	1.803
1m	3.526	1.926
2m	2.105	1.449

Table 1: 7pt Likert scale discomfort ranking. As interpersonal distance increases, discomfort decreases, matching previous work [8].

is then asked to walk towards an avatar 2m away until they become uncomfortable. These tasks are adapted from previous work [8].

Collaborative tasks and survey The participant is instructed to complete collaborative tasks using different personal space bubbles. They are told to avoid invading the other avatar's personal space while completing the tasks as quickly as possible. A restaurant kitchen is used to host familiar tasks in an immersive workplace environment (Figure 2). The first task, making a sandwich, simulates passing objects by requiring avatars to hand each other ingredients. The arranging task requires avatars to occupy shared space while placing objects. One avatar puts fries on meal trays, while the other puts drinks on each tray. The next task, a high five, was selected as a common social gesture. After each round of tasks, participants are surveyed on task load, personal space invasion anxiety level, naturalness, physical presence, social presence, and team cohesion.

3 RESULTS

We recruited 21 female participants from the university community. Two participants were excluded due to technical problems and motion sickness. The remaining 19 participants' data were used.

Comfort Baselines Table 1 reports the average responsese to the proxemic comfort baseline task. As distance increases, the self-reported discomfort decreases, which is consistent with prior literature [8]. A one-way ANOVA shows a significant effect between the three distances with $F(2,54) = 14.7$, $p < 0.01$, $\eta_p^2 = 0.35$.

Self Reported Metrics The questionnaire used to gather self-reported metrics included questions from the NASA Task Load Index, which address perceived difficulty [6] , personal space invasion anxiety level scale, which address discomfort [4], and other questionnaires. Metrics were generated based on the averaging computation required for each group of questions, and are shown standardized in Figure 3. We did not find any significant differences for our questionnaire measures. We expected the bubble type to influence the perceived difficulty and naturalness of interactions. While the means' ordering follows our predictions (the task is perceived as most easy and natural for the body-shaped bubble and most difficult and unnatural for the cylindrical bubble), none of these differences reached significance. Team cohesion metrics are higher for body shape than cylinder. The results indicate that participants felt their personal space was protected with all bubbles.

Performance Metrics We computed completion time, number of bubble violations, duration of bubble violations, and path length for each task. We did not find significant differences for these measures.

4 DISCUSSION

We have examined a popular tool to alleviate personal space violations in virtual reality: the personal space bubble. We have prototyped an experiment to evaluate different bubble designs based on safety (perceived personal space invasion anxiety, actual number of bubble violations, etc) and utility (task completion time, perceived naturalness of interactions, perceived team cohesion). While the trends exhibited by this exploratory study are promising, they are not statistically significant. As we are examining novel bubble designs, we did not have previous data to compare to.

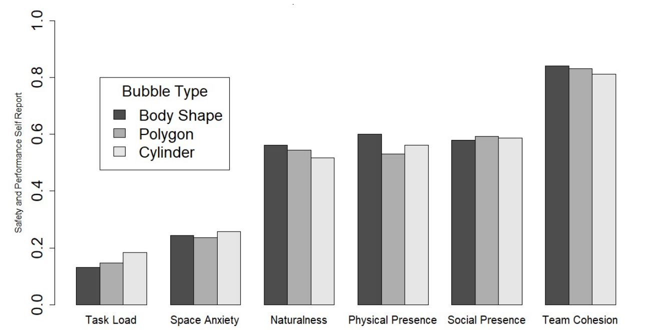

Figure 3: Results to questionnaire for our three types of bubbles.

Limitations Experimental design choices may have impacted proxemic comfort. We constrained our recruitment to only female participants, as literature suggests gender's impact [3]. Mixed gender interactions may solicit larger effects. The mannequin avatar could also impact this aspect. Our experiment only investigated bubbles that provided informational feedback. If the bubbles actually blocked or pushed away the other avatar, we may have seen stronger effects on performance metrics, naturalness, and team cohesion.

Our experiment was based around collaborative workplace tasks. However, we did not simulate any form of harassment. Because protection against harassment is a primary usage for personal space bubbles, this omission may have diminished our findings.

Future Work Though personal space bubbles are hailed as an obvious tool for preventing certain types of physical harassment, it is worth considering that obstructing movement is a kind of harassment too. When considering the usage of bubbles, in particular, bubbles with more active consequences for invasion, it is important to recognize that bubbles could inadvertently become a tool for harassment. Investigating these issues is going to be crucial for creating virtual experiences that are safe and productive for all users.

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