# Digital Proxemics: Designing Social and Collaborative Interaction in Virtual Environments

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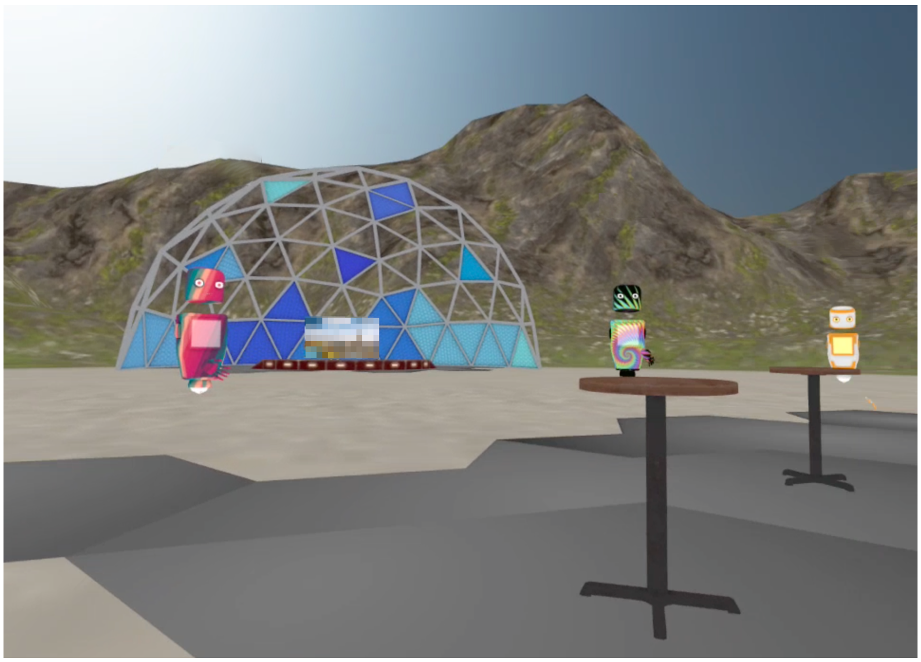

Fig. 1. Mozilla Hub's Outdoor Meeting Space.

Our behaviour in virtual environments might be informed by our experiences in physical environments, but virtual environments are not constrained by the physical. Instead of replicating properties of physical spaces, we can manipulate dynamic environmental, aural, and social properties in virtual experiences that diverge from reality. This paper lays a foundation for *digital proxemics*, which describes how we use space in virtual environments and how the presence of others influences our behaviours, interactions, and movements. First, we describe the open challenges of digital proxemics in terms of human activity, social signals, audio design, and environment. We explore a subset of these challenges through an evaluation that compares two audio designs and two displays with different social signal affordances (head-mounted display versus desktop PC). We use a mixed-methods approach combining interaction data from an instrumented virtual environment with in-depth interviews. Our results quantify the impact of increased embodiment and audio acoustics in social VR on proxemics.

CCS Concepts: • **Computer systems organization** → **Embedded systems**; *Redundancy*; Robotics; • **Networks** → Network reliability.



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Additional Key Words and Phrases: Virtual Environments, Digital Proxemics, Social Signal Processing, Qualitative Methods.

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## 1 INTRODUCTION

*Digital proxemics* describe how we use space in virtual environments (VEs) and how the presence of others influences our behaviours, interactions, and movements. Proxemics in *physical environments* has been extensively researched [15, 19, 22]. Research on the relationship between proxemics and technology is also well established [17, 26]. *Digital proxemics* concerns a distinct and emerging area of research [5, 24, 42] that concerns itself with how social proximity is perceived and acted upon in malleable virtual environments. Recent advances in the availability, fidelity, and immersive displays for experiencing virtual environments have expanded the possibilities for research in this area.

Understanding how we use space in VEs builds upon but is distinct from proxemics in physical settings. VEs do not have the constraints of physical environments and can be manipulated and reconfigured in real time. For example, the size and layout of virtual rooms can be altered during interaction, changing the perceived crowdedness or cosiness of a virtual space. Audio parameters can be changed to amplify a speaker and minimise noise from the audience. Engineering successful virtual experiences will depend on being able to make such changes with intention and design, where poor decisions will result in unfit or unusable spaces. Additionally, the range of affordances and social cues available in virtual environments is dramatically different from physical environments. We experience a VE through an avatar, which may have less articulation than our own bodies. The field of view may be narrower than human vision, giving a lower bandwidth visual channel to perceive our surroundings. Senses that play a key role in physical proxemics, such as body odour and skin warmth, are often completely missing from current VEs. The range of social signals possible in a VE may be limited, but control over how we present ourselves in a VE is much more flexible than in physical settings. For example, pre-rendered animations performed by avatars allow us to give off desired signals without physically performing them. Physical proxemics provide the inspiration, but the beyond reality capabilities of VE present a new challenge for designing virtual experiences.

In this paper, we lay a foundation for *digital proxemics*, discussion the open challenges in this emerging area in terms of human activity, social signals, audio design, and environment design. Understanding the patterns of behaviour for the *activities* we intend for virtual environments provides a key starting point [15, 22]. Do we want to facilitate serendipitous networking events [34] or focused small group discussions [2]? These patterns of behaviour may unfold differently in virtual environments when we consider the *social signals* available in the VE. Audio and speech design rep finish this section introducing each factor a bit.

To begin exploring *digital proxemics*, we conducted an evaluation in a virtual environment using Mozilla Hubs[1], an open source VE platform that runs in a standard browser. Our evaluation compared two audio designs and two display types supporting different affordances for social signals. The first audio design, called "cocktail," simulates the physical audio environment of a cocktail party where background talk is audible throughout the VE. The second audio design, called "bubble," silences background talk beyond eight meters. We also compared desktop PC display to head-mounted

[1]Mozilla Hubs: https://hubs.mozilla.com

display (HMD), where HMD users had greater expressivity through head movements and tracked hands compared to desktop PC keyboard controls. add signposting to hypoth and results here

The contributions of this paper are:

- Proposed research space for*digital proxemics* organised into key factors of activity, social signals, audio, and environment.
- Comparison of behaviour using an HMD versus a desktop PC, quantifying different behaviours in terms of personal space and social signals demonstrating attention
- Comparison of two audio conditions, measuring the impact of background noise on group proximity.

## 2 RELATED WORK

### 2.1 Proxemics in Physical Spaces

This research builds on Hall's foundational work on proxemics [19], which describes human proxemics in face-to-face interactions. Proxemics in physical spaces is based in how people perceive distance using their eyes, ears, skin, and even noses [19] to determine a comfortable physical distances. How much of another person's body is visible in your field of view, how loud you perceive their voice to be, whether you can feel the heat of their body, or even smell their cologne, all factor into negotiating personal space during face-to-face interactions. This sense of personal space is dynamic, and may change depending on context, culture, and behaviour.

Hall defines four proxemic zones; intimate, personal, social, and public [19]. In the *intimate* zone (< 0.46 meters), physical contact may heighten or distort social cues, field of view will be close to the other person's face, you might feel their breath or the heat of their body. In the *personal* zone (0.46–1.2 meters), you can still reach out and touch someone but physical contact is not constant. This relative closeness makes facial expressions, movements of the eyes, and other small movements more pronounced. In the *social* zone (1.2–3.6 meters) you would not expect any physical contact and can view the other person's whole body more fully as they move further through this zone. In the *public* zone (> 3.6 meters) there is decreasing visibility of the face and audibility of the voice but more of the periphery opens up.

The proxemics of face-to-face interactions have been analysed in terms of attributes beyond physical distance. Kendon describes *F-formations*, introducing the relative orientation of a group as an important attribute of proximity. F-formations arise during encounters that are sustained between two or more people in close proximity where they are oriented towards a shared space with exclusive, direct, and equal access [22]. Goffman's approach has less emphasis on physical spacing and instead analyses the way people allocate and demonstrate their attention and focus [16]. Goffman's research describes face-to-face interactions as *unfocused* or *focused*, with special consideration to focused interactions where groups gather together to collaborate on a single goal or point of attention. Focused interactions can be complex, with tight or loose social regulations, explicit and implicit boundaries for participation, and different expectations or affordances for involvement [16]. Whyte focuses on the design and affordance of urban spaces [40], considering how the availability and design of sitting space, relative position of the street, and exposure to sun and wind change where and how people gather and meet in public settings. Whyte's research on *effective capacity* and perceived *crowding* combine physical space design with human proxemics. Physical capacity can be very different from *effective capacity* when space is designed well, for example small spaces like Greenacre Park in New York can feel less crowded because the loud water feature masks the noise of other people. Whyte discusses how effective capacity is dynamic and self levelling based on proximity of others, comfort, and amenities.

Translating physical proxemics into VEs presents challenges because social and environmental cues may lower fidelity or completely absent when translated to the virtual. Olfaction and scent play a significant role in physical proxemics, but are challenging to incorporate in virtual environment. Haptics have similar limitations, with capabilities for tactile, thermal, and force feedback in virtual environments. Audio experienced through simulation and loudspeaker may be significantly different from audio in physical environments [37]. On the other hand, proxemic cues in virtual environments may be deliberately manipulated, distorted or enhanced to alter the social dynamics of a virtual space.

### 2.2 Interaction and Personal Space in Virtual Environments

In HCI, proxemics have been applied to the design and analysis of interactive systems [17] and to understand how technology plays a role in physical proxemics [26]. There is an established body of research exploring how social signals from the physical world translate into the virtual, and how this impacts user experiences. The range of affordances, particularly around embodiment and the social signals available in different platforms, is a key factor in how a VE can support collaboration and social interaction [9]. Benford et al. look holistically at embodiment in virtual environments [4], discussing a broad range of issues including how users can demonstrate their presence, position, orientation, facial expression, and identity. Many of the issues, such as assessing whether another person is *actually* present, persist in current VE applications. Guye-Vuillème et al. investigated non-verbal cues in a collaborative virtual environment, allowing participants to trigger postures, facial expressions and gestures [18]. Bowers et al. focused on talk and turn taking given limited affordances for social signals in a VE called MASSIVE [6], finding that participants quickly adapted to the abilities of the "blockies" avatars to anticipate turn-taking and negotiate interactions. Moore et al. consider how environment design impacts of social activity in virtual space, identifying accessibility, social density, activity resources, and hosts as key factors and creating successful virtual spaces [28].

Personal space in virtual environments is a key issue for digital proxemics, especially when platforms provide inconsistent mechanisms for establishing and protecting personal space. Hecht et al. completed comparisons on the shape of personal space in physical and virtual environments, finding that personal space was roughly circular and consistent between real world and virtual encounters [20]. Wilcox explored discomfort when personal space is violated in virtual environments, demonstrating significant negative reactions comparable to the same experience in physical environment [41]. Llobera et al. analysed physiological arousal using skin conductance when participants were approached by virtual characters at different proximities [24],demonstrating heightened physiological arousal the closer virtual characters approached. Bailenson et al.[3] explored how gaze impacted personal space between participants and virtual agents, finding that participants avoided collisions with the virtual agent. The gaze of the virtual agent also impacted their performance in a memory task in comparable ways to physical observers. Podkosova et al. explored proxemics and locomotion when participants were in a shared virtual environment where some participants where physically co-located and others were distributed [32] For distributed participants, collisions were more common and sense of co-presence lower than between co-located participants.

Proxemics have also been used to enforce personal space and protect users in a virtual environment. Pohl describes how proxemic zones could be used to enforce rules on which objects and agents are allowed in personal space [33]. McVeigh-Schultz et al. analyse the properties of a range of virtual environments in terms of embodiment, social mechanics, and functions for shaping and enforcing social norms to prevent harassment [27]. The ethics of "immoral behaviour" and misrepresentation remain open challenges in virtual environments [7].

### 2.3 Methods for Digital Ethnography in Virtual Environments

Evaluating interaction in virtual environments draws heavily from ethnography, with a significant body of work using observation and interview methods to analyse user experience. Ethnographic methods have been applied to virtual environments like World of Warcraft [30], There [8], Second Life [12], and multi-player dungeons [1]. These approaches often make use of *participant observation*, where researchers actively engage with the environment and other users to gather qualitative data on their experiences.

Virtual environments also afford automatic logging and collection of quantitative data. In commercial platforms like Second Life, researchers have used bots to log extensive data about interaction and movement through the virtual world [38]. For example, Varvello et al. found that avatars in Second Life formed small groups similar to physical settings using this quantitative approach [38]. Friedman et al. also used bots in Second Life [12], using proxemics to analyse behaviour when players were approached by logging bots and forming small groups. Fraser et al. completed a lab study to compare virtual and physical environments in terms of field of view, haptic feedback, and latency [11]. Schroeder et al. describe two quantitative methods using interaction logs and manually tags data for statistical analysis of interaction in a VE [35], focusing on categorising activity types and occurrences of events. Combining qualitative and quantitative methods using observation, logging, interviews, and surveys have also proven effective. Ahn et al. completed a survey to analyse user experience at an academic conference, focusing on social presence and satisfaction with the virtual conference format[2]. Williamson et al. completed quantitative logging with qualitative interviews to analyse interaction in a workshop event [42]. Le et al. gathered quantitative data through surveys and logs across multiple platforms and qualitative observation data to analyse comfort, motivation, and experience during an academic conference [23].

## 3 DIGITAL PROXEMICS

Understanding *digital proxemics* will change the way we design interaction for virtual environments, creating opportunities for richer and more varied social experiences. In virtual environments, we can manipulate interaction to facilitate social and collaborative activities beyond those possible in physical environments. To meaningfully engineer these VE experiences, we need to understand how people react to social cues in virtual environments, how changing virtual parameters impacts behaviour, and how to apply these to construct effective virtual social interactions. For example, what parameterisation promotes the most serendipitous interactions, or the most focused ones? Which configurations encourage equal participation, or alternatively give leaders more power? Understanding how to design and configure virtual environments to promote or constrain social behaviours is the core of *digital proxemics*. Taking inspiration from physical proxemics, we propose a research space for *digital proxemics* based on activity, social signals, audio, and environment.

### 3.1 Activity

The structure of social activities provides a starting point for analysing *digital proxemics*. This might include the number of focus points in a shared space, number of participants, and expectations around participation. Designers often aim to facilitate specific activities like presentations, networking events, or small group collaborations. The needs and constraints of a presentation from a single person to a large group are dramatically different than a networking event with no fixed focus point. Goffman describes interaction as *focused* or *un-focused* [16]. Kendon further studied *focused* interactions in substantial detail [22].

*3.1.1 Unfocused Interactions.* Unfocused interactions happen where people are co-present but not engaged in a shared activity; for example, wandering about a networking event. Unfocused interaction is primarily non-verbal, but people may "give off" complex behavioural signals as part of managing co-presence. Their posture and facial expression could indicate availability for interaction. Their position and body orientation could communicate their intention to join an existing group. Well engineered unfocused interactions play a key role in familiarisation with a virtual environment, serendipitous encounters, and forming groups.

*3.1.2 Focused Interactions.* Focused interactions involve groups engaged in coordinated activities; for example conversing as a group or listening to a presentation. Focused interactions cover a broad range of social activities [22], which may or may not have highly formal rules around access, turn taking, attention, and participation [16]. Understanding the formal and informal rules of the intended activity and how social norms are negotiated can inspire VE designs. For example, a presentation with a single focus point may be improved by amplifying the presenter's voice and muting observers. In less structured focused interactions, for example breakout groups, more flexible affordances might be needed.

### 3.2 Social Signals

In all interactions, the non-verbal signals we continuously *give* or *give off* are a rich source of information that is constantly interpreted by others. These signals can be understood in terms of information theory [22], where some have greater bandwidth, some are more noisy, etc. The range of social signals available in a VE can be dramatically different than face-to-face interaction, and we are often missing signals (notably scent [19]) or are restricted to transmitting them in limited or awkward ways [5].

The design of the VE or the mode of interacting with the VE can impact users' performance and perception of social signals. Many VEs support interaction on both desktop PC and head-mounted displays. The additional expressiveness of hand tracking or ease of visual scanning with an HMD create very different experiences [42]. In physical spaces, Kendon discusses the ease of maintaining mutual eye contact, of positioning the body, and of gesturing, and how easy it is the observe these in turn [22]. There may not be one-to-one relationships with these signals when they are translated to the virtual. Is some ways VEs can enhance our perceptions, for example notifications when others enter and exit a room. Such signals may be more accurate and more effective than the physical equivalent of watching the door.

*3.2.1 Body Position and Orientation.* The basis of physical proxemics is relative body position. Refinements such as F-formations introduce relative orientation. These attributes can directly translate to a VE—avatars have a "front," they take up space, they can move. But there is also potential for beyond reality interaction, for example presence in multiple locations, instantaneous movement, and omni-directional sensing. Matching these "beyond reality" capabilities to human social dynamics represents an open design challenge for interaction in VEs.

*3.2.2 Articulation of Head, Body, and Limbs.* The range of non-verbal communications affects the experience of a VE [4], but how these are generated or performed does not need to be a 1:1 relationship with physical movement. For example, *Emotes* are user-triggered canned animations (such as waving, dancing or other gestures) to communicate non-verbally. Emotes require less effort and give individuals more control than physical actions.

*3.2.3 Facial Expression.* Hall describes the key role that facial expressions play in intimate and personal proxemic zones [19], but the effects of restriction on field of view in close proximity will be different in a VE. Facial expression is also commonly absent or weakly presented in VEs, although it is increasingly being explored [36].

*3.2.4 Physical Appearance.* The body-ownership and embodiment of avatars has been extensively researched [10, 25, 31]. The ability to customise appearance, and the range of options available, will also have an impact on *digital proxemics*. For example, previous work has found differences in how users maintain space between humanoid and abstract agents in virtual environments [24].

### 3.3 Speech and Audio Design

Audio is one of the main modalities (after visual) for engaging in a VE, with many possibilities for beyond-reality interactions. The production, perception, and interpretation of speech has been widely researched in physical and simulated environments. Thery et al. found that binaural audio presented over headphones and loudspeakers differed significantly in perceived reverberation and listener envelopment [37]. For example, these changes in sound perception could have significant impacts for how the 'cocktail party effect" [43] is experienced in physical or virtual environments. Gil-Carvajal evaluated audio perception when presented with incongruent visual or auditory cues [14], finding the mismatches could significantly disrupt distance judgements.

Numerous approaches have been used for simulated and propagating sound in virtual environments [13], but how these impact behaviour and user experience is still an open challenge. The ability to dynamically manipulate audio parameters makes this an interesting part of digital proxemics, is straightforward to achieve in current VEs, and potentially disrupts our perception and social signals in ways that needs careful design. For example, a group needing privacy in a physical setting might huddle in a corner. In a VE, one could create a private zone which may or may not give off signals for privacy to others. Audio design could also create super powers, for example whispering across distances, creating instant megaphones, and breaking apart the relationship between distance and audibility in both useful and confusing ways.

### 3.4 Environment Design

How we design space is crucial to how we use space [21, 40]. Virtual environments diverge from physical environments in significant ways, creating infinite possibilities in terms of form, malleability, scale, and functionality. Virtual environments may also lack familiar aspects of physical environments, where collisions, boundaries, and other physical properties may be limited or completely absent. Moore et al. describe the challenges of designing successful virtual places in face of limitless possibilities [28], analysing how the accessibility, social density, activities, and hosts impact the success of virtual spaces. Moore et al, discuss the tendency to create complex spaces because *we can,* but complex or expansive spaces often make poor virtual places.

Virtual environments also afford beyond reality designs that could be leveraged for better interactions. For example, non-euclidean virtual environments [29] can be navigated in ways not possible in physical environments. Imagine a hallway to breakout rooms that is long to enter but short to return. Would increased travel time to breakout rooms aid in group formation and cohesion? Playing with virtual space is an open challenge in digital proxemics where our models of proximity are still grounded in physical environments.

## 4 DESIGN AND EXPERIMENT

As our first steps in exploring *digital proxemics*, we identified two conditions which can affect how small group discussions work in a virtual environment: audio attenuation model and display modality. We compared audio models where background noise is always present versus background noise silent beyond 8 meters. We also compared desktop PC display versus head-mounted display. We selected these conditions based on three hypotheses:

Table 1. Groups of participants were *audio conditions* and *interaction modality*. The social conditions (i and ii) and audio conditions (a) Cocktail (or Inverse) and (b) Bubble (or Exponential) are detailed in § 4.2. Each group consists of two parts (for example 1.1 and 1.2 represent both discussion groups of 3 people each in Group 1).

| *Audio Condition* | (i) **Immersive VR** | (ii) **Desktop PC** |
|---|---|---|
| (a) **Cocktail** | Group 1 | Group 3 |
| (b) **Bubble** | Group 2 | Group 4 |

**H1** People using HMDs will make more use of personal space, collaborating at a further distance due to hand gesturing.

**H2** People using HMDs will find collaboration easier when they can express attention and maintain peripheral awareness through head movement.

**H3** People with background noise will find collaboration harder .

### 4.1 Virtual Environment

We used the open source Mozilla Hubs as our experiment's VE. This allowed us to easily modify the client code running in the HMD or desktop browser. This includes instrumenting avatar's positional data (x, y, z), forward vector, and various state flags (flying, muted, etc.) at each frame. We built our data collection platform for Mozilla Hubs by modifying a previously open sourced Hubs research collection framework [? ]. All of our code, data, and analysis scripts are open sourced[2].

We chose to us a single environment during this experiment. We used a stock virtual room in Hubs called "Outdoor Meetup". We added elements specific to our evaluations, such as links to the information sheet and questionnaire and worksheets. The Outdoor Meetup space is a large outdoor environment measuring... and has been used an several different evaluations...i think VR used it, and we def did so we can cite a couple things not all our own work!.

### 4.2 Experimental Conditions

We ran a between-subjects evaluation with two factors: audio design and social signals. For audio design, we compared an distance attenuation model where background talk is audible (inverse model) or inaudible (exponential model). We compared desktop interaction to HMD interaction to compare different affordances for social signals.

*4.2.1 Audio Design.* We ask if making the audio unnatural—not following the a simulation of physical audio transmission—affects social collaboration in virtual environments. Many features affect speech transmission and intelligibility [? ], and we focused on the attenuation of background noise.

We ask if audio isolation will create a corresponding feeling of social isolation. We measure how people establish interpersonal distances in conversations in the presence of background sound. To control background sound levels, we adjust Hub's attenuation model to follow either an inverse or an exponential model.

Audio Condition a. *The Cocktail Inverse Model attenuates audio similarly to the default Hubs configuration and the "ideal audio" simulation optimised to flatten at the "public distance" zone. The effect is similar to background chatter one would pick up at a cocktail party or other social gathering.*

[2] Available upon publication to maintain anonymity.

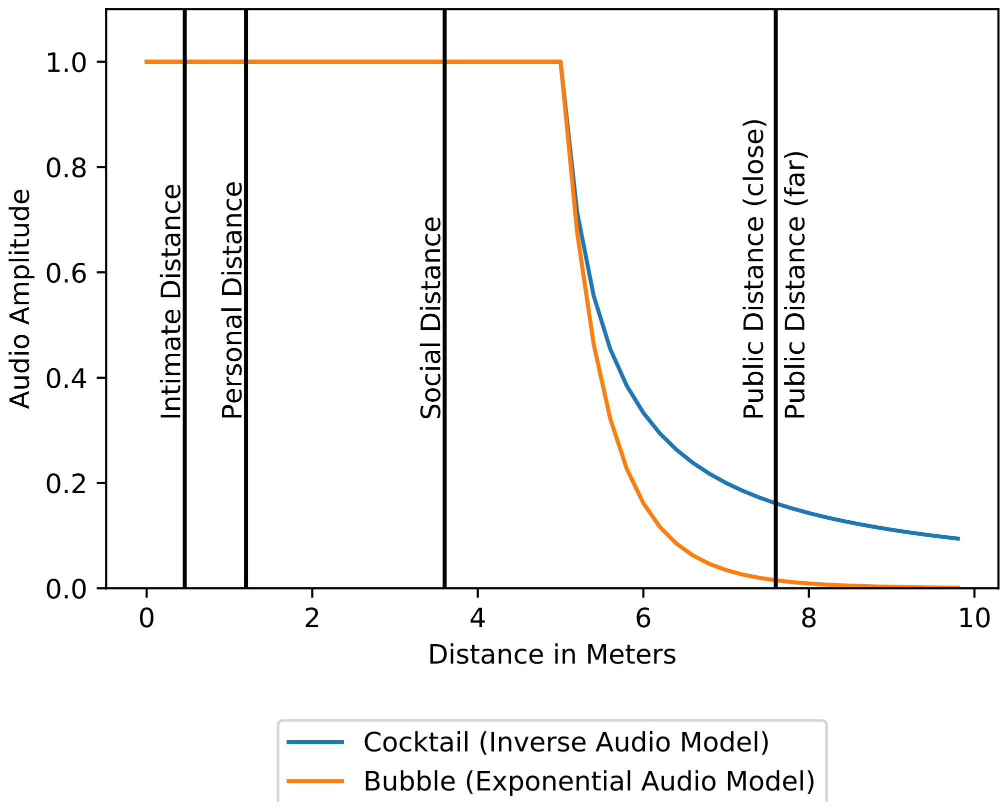


Fig. 2. Attenuation per meter in the two audio conditions (linear scale). Vertical lines indicate Hall's zones [19]. While the Cocktail/Inverse condition a asymptotically approaches $x$-axis after the public distance, the Bubble/Exponential b model descends faster after 5 meters and crosses the $x$-axis at 10 meters.

Audio Condition b. *The Bubble Exponential Model has a faster decay and silences audio beyond a fixed distance threshold. This is similar to being inside an audio bubble or wearing background cancelling headphones.*

Condition (a) is close to the attenuation model in the physical world. Condition (b) creates an audio isolation field around each avatar, unlike that experienced in the physical world (however, an analogous effect can be seen in in museums with hyberbolic shielded speakers pointing down to make listening areas around media installations). Figure 2 shows the audio attenuation curves for the two conditions.

*4.2.2 Social signals.* We next ask if the interaction device affects proxemics. The device constrains the social signals that can be communicated and perceived. We compare interaction with a desktop PC (controlled by mouse and keyboard) and a head-mounted display with hand tracking. Previous work has indicated the embodiment and something here to say…?.

Table 2. The collaborative task worksheet given to the participants of each group.

## Sea Survival Worksheet

Consider the following 15 items and their usefulness if you were lost at sea. As a group, select the five most important items you would choose to maximise your chances of survival. You must agree as a group on the final list you would select.

- Sextant (A navigation instrument for measuring angular distances)
- Shaving mirror
- Five-gallon can of water
- Mosquito netting
- Once case of army rations
- Maps of the Pacific Ocean
- Seat Cushion
- Two-gallon can of oil-gas mixture
- Small transistor radio
- Shark repellent
- Twenty square feet of opaque plastic
- One quart of 160-proof Puerto Rican rum
- Fifteen feet of nylon rope
- Two boxes of chocolate bars
- Fishing kit

Social Modality i. *This condition uses an Oculus Quest HMD. Immersive experiences with HMDs allow avatars to express natural (tracked) head movement that tracks to the HMD as well as hands which will animate and move about the space as a user gestures and talks. This hand space may create an added personal perimeter to an avatar.*

Social Modality ii. *This condition uses a convention desktop PC and has no head movements (aside from voice amplitude modulation of the avatar) and no hands.*

### 4.3 Small Group Task

We chose a consensus seeking task [39], where people can verbally engage with each other as single group or multiple sub-groups. This is in contrast to puzzle-based tasks which require interaction with an object or device. The task was making a lost at sea survival item list. Participants are asked to imagine they are about become lost at sea, and are asked to jointly select five items from a list of fifteen items that would maximize their chance of survival. Table 2 details the full task and items the participants could to choose. Each group consisted of six people with two authors facilitating the discussion. The experiment was divided into four independent groups; the product of the two audio conditions and the two social signal conditions.

We recruited participants through mailing lists, social media, and local networks. Each prospective participant was given a short screening questionnaire and the selected participants were grouped (see Table 1) by their interaction modality (Oculus Quest HMD versus desktop computer) and by the audio condition (described later in section something). The sessions lasted 45 minutes and participants were monetarily compensated for their time. Participants were instructed to arrive ten minutes before session start time to complete technical checks, familiarise themselves with the room, and were advised to use a network with sufficient speed (e.g. avoid slower public WiFis). The experiment was reviewed and approved by an institutional ethics committee.

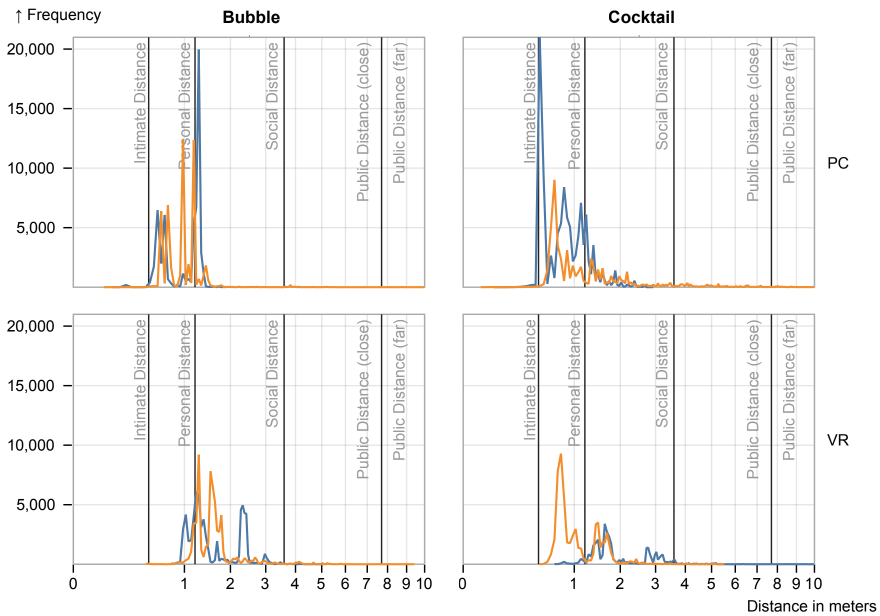


Fig. 3. During small group discussions, PC participants stood closer together regardless of audio mode mostly occupying intimate to personal distances. By contrast VR participants maintained personal to social distances. The two line colors denote the sub-groups in each condition.

### 4.4 Results

Each group's session ran for 45 minutes. What was the protocol exactly?

In Mozilla Hubs, each avatar in the VE has an individual frame rate that varies depending on the hardware's speed and network condition. This creates a variable rate per avatar (participant). To correct this, we resample the time series from each participant to 30 frames per second (fps). After resampling, there were 3,034,125 events measured across the four groups of eight people (six participants and two facilitators). Running the study? How much data? Interviews? This analysis is based on (some stats about the data). All quantitative analysis was completed…

Start with general overview and commentary.

*4.4.1 Audio Design.* The key difference in our two audio conditions was the presence of background noise and chatter when the participants split into two groups. In the cocktail condition (a), participants could always hear the other group in the background no matter how far apart they stood. In the bubble condition (b), participants would not hear the other group at all if they stood more than eight meters apart. Although background noise would be realistic in a physical environment, we hypothesised that the bubble of background noise would promote distance between avatars (and provide fewer distractions for small group focused interactions). Contrary, by modality, we found VR participants (i) kept more of a personal to social distance than PC participants (ii) regardless of the audio condition. Figure 3 details each group's distances during the small team discussion.

*4.4.2 Social Signals and Attention.* When interacting with the VE using a head-mounted display, participants have more affordances for giving off social signals, and this was reflected in how they positioned themselves and demonstrated their attention during the small group discussions. Figure 4 visualises a top-down view of participants’ perspective in VR versus PC, including the field of view and active speaker. Figure 4 demonstrates how participants in VR moved their head to kept other participants in their field of view, especially when others were speaking. In contrast, PC users maintained a more static field of view and did not always turn to face the active speaker. In small groups, participants allowed others to stand closer to them, which was even more pronounced in VR (as described above). In the larger group, participants were more varied, with a larger sense of personal space extending well into the social proxemic zone.

*4.4.3 Personal Space in Small and Large Groups.* To measure personal space by group size, we analysed the closest standing person while interaction in small and large groups. Figure 5 compares the nearest person for large and small groups in VR and PC. The smaller groups did create closer formations with PC participants gathering at a more intimate distance over HMD (VR) users who kept a personal distance. For large groups interaction, we see a similar pattern with some participants in both groups however many of both participants chose to keep more distance by comparison to the small group.

## 5 DISCUSSION

Feild of view is an interesting issue...

## 6 FUTURE WORK

All of the data gathered during this experiment used the same virtual environment, although future work should explore how environment design also influences behaviour in virtual environments.

## 7 CONCLUSION

Understanding digital proxemics...

how would you design speed dating in a VE???

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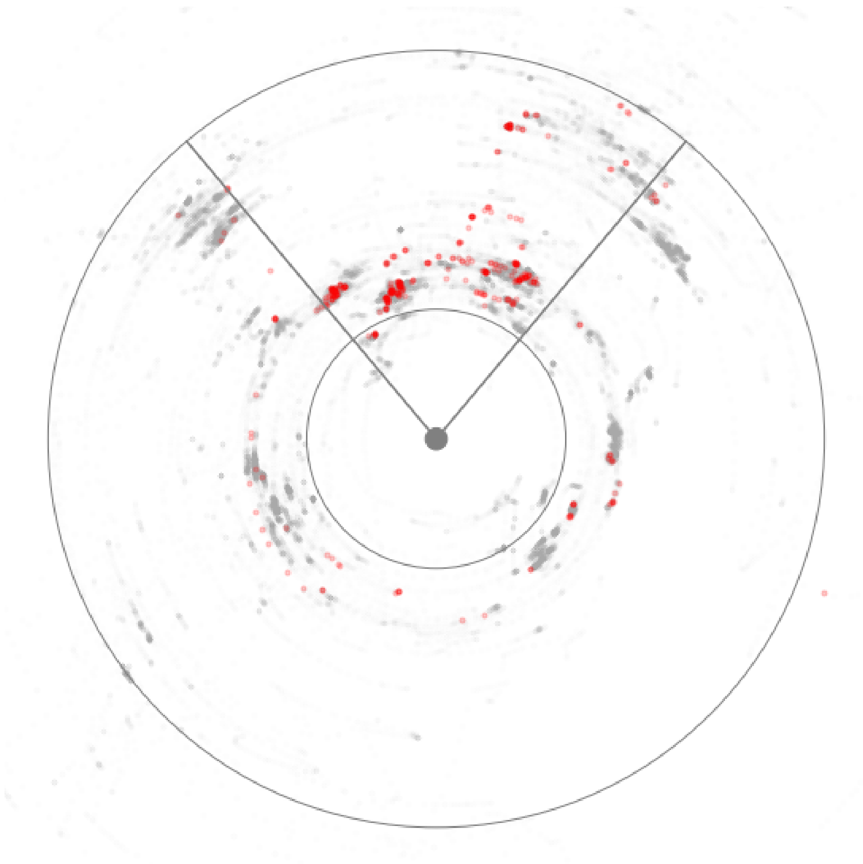
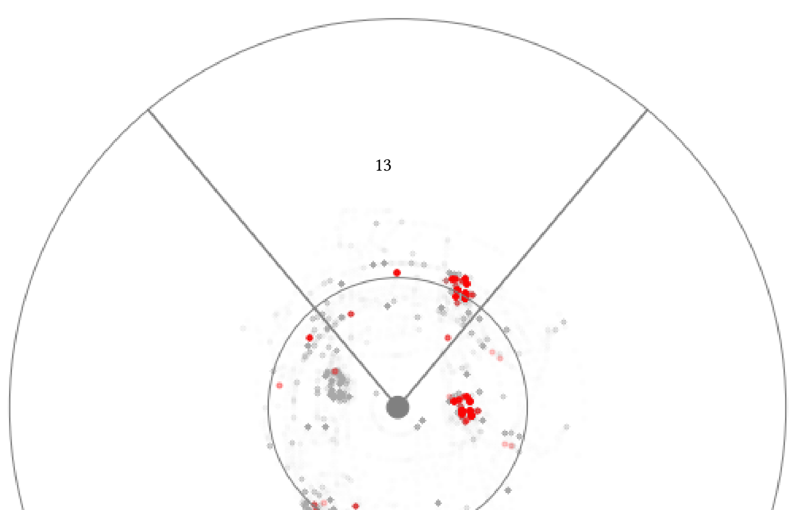
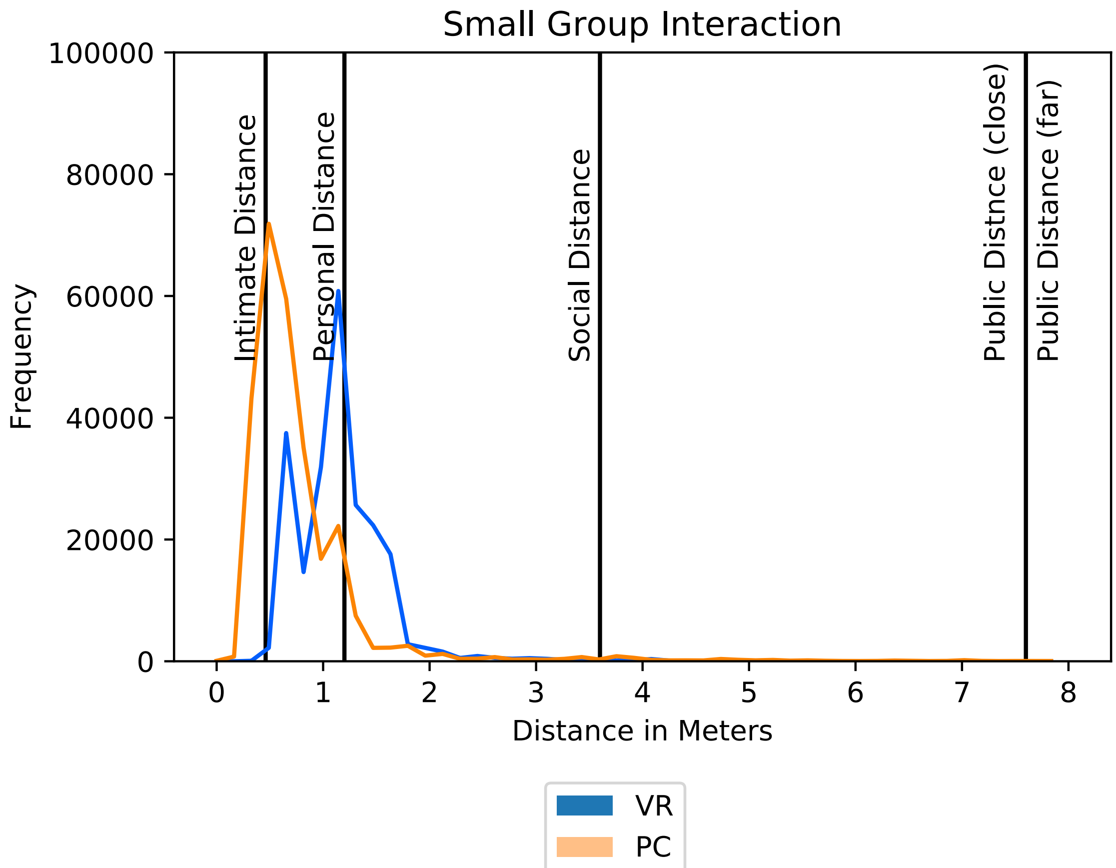
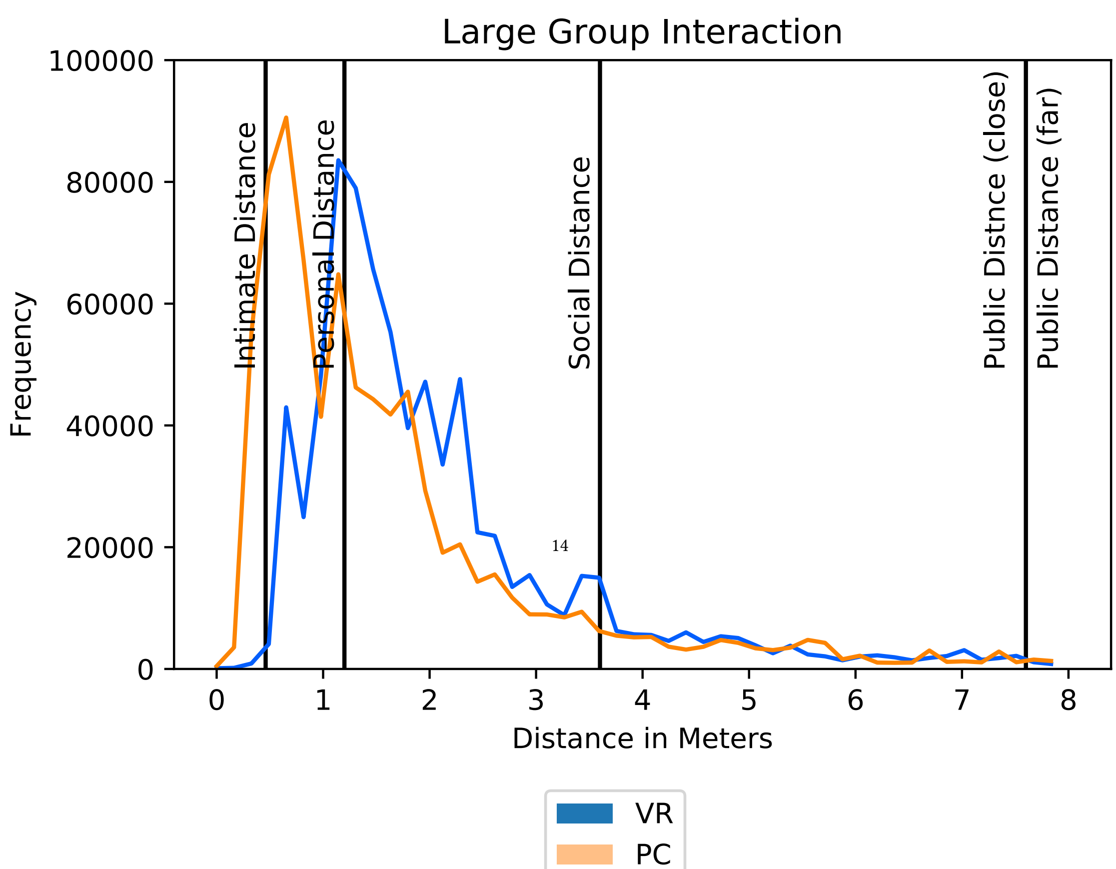


(a) Small Group VR




Small Group Interaction
Frequency
Distance in Meters
Intimate Distance
Personal Distance
Social Distance
Public Distnce (close)
Public Distance (far)
VR
PC

(a)


Large Group Interaction
Frequency
Distance in Meters
Intimate Distance
Personal Distance
Social Distance
Public Distnce (close)
Public Distance (far)
VR
PC

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