Alone Together, Together Alone: The Effects of Social Context on Nonverbal Behavior in Virtual Reality

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Abstract

Social virtual reality (VR), by definition, focuses on people, using networked VR systems to bring avatars together. Previous studies have examined how different factors affect social interaction, in small groups such as dyads or triads. However, in a typical social VR scene there tends to be dozens of avatars, even those not directly interacting with a given user. Furthermore, beyond the virtual environment, VR users are also situated in various immediate physical social contexts. In two field experiments, we investigate how the presence of virtual and physical people contextualize and influence nonverbal behaviors. Study 1 examines *virtual context* and asks how interacting with others in a private or public virtual environment influences nonverbal outcomes during interactions in a social VR platform. Across two sessions, participants (n = 104) met either in a private virtual environment with their group members alone or in a public environment surrounded by four other groups. Results showed that participants moved their avatars slower and stood closer to group members in public versus private environments. Study 2 examines *physical context* and asks how interacting with virtual others while physically together or alone influences nonverbal behaviors. Participants (n = 61) met in virtual environments while they were in either a shared physical environment or separated physical environments. Results showed that, compared to remote participants, participants who were physically together moved their bodies more slowly, but their avatars faster. Moreover, there was more mutual gaze among remote participants. We discuss implications to theories of social influence in VR.

Keywords: *virtual reality, social virtual reality, social interaction, context, small group dynamics*

Introduction

As communication media technologies continue to advance and introduce new ways of interacting with one another – either physically, virtually, or potentially in other ways – understanding how individuals affect one another in these new mediums is critical. One such medium is social virtual reality (VR), which are computer-generated, networked simulations of environments that facilitate human interaction through 3D avatars. To understand how people behave and engage with one another in such virtual environments (VEs), Blascovich and colleagues (2002) developed the social influence model – a theory based on Allport's (1954) classic definition of social psychology that people's thoughts, feelings, and behaviors are influenced by the actual, implied, or imagined presence of others. According to Allport's definition, people are directly and indirectly influenced by the presence of others, which affects their affective, cognitive, and behavioral social responses.

Compared to other communication technologies, VR is a unique medium such that it is immersive (i.e., generates realistic experiences that foster the feeling of presence) and allows for embodiment (i.e., creates a psychological connection between an individual and their avatar, allowing them to feel that the body that they are in is their own) (for a history and list of affordances, see Basu, 2019). Such affordances allow people to convey and pick up on nonverbal bodily cues such as nodding, facial expressions, and fidgeting (Slater, Sadagic, Usoh, & Schroeder, 2000). Furthermore, the virtual beings that people can interact with within these environments – avatars (i.e., human-controlled virtual beings) or agents (i.e., computer-controlled virtual beings) – can vary in terms of their visual, behavioral, and interactional realism, introducing more dimensions to consider when evaluating how people socially interact with others in VR (Garau, Slater, Pertaub, & Razzaque, 2005; Swinth & Blascovich, 2002).

The social influence model, in light of these affordances, identifies five factors that govern the way people engage with others in VR. The first factor, *theory of mind*, refers to the beliefs about the sentience of others. Depending on this belief, people can treat others as if they are not there or interact with them as they would in a physical interaction. The second factor, *communicative realism*, refers to the movement and anthropometric and photographic realism of others, with people being more likely to be influenced by realistic others. The third factor, *response system level*, refers to the automatic (e.g., reflexes) and deliberate (e.g., purposeful) responses people have based on the beliefs they have about others. The fourth factor, *self-relevance*, refers to how people interact with others differently depending on the degree of relevance of the interaction and the type of roles they play. The fifth and final factor, *context*, refers to how people's behaviors depend on where they are. Together, these factors underscore that people change their behavior based on the beliefs they hold about others, themselves, and the situation (Blascovich & Bailenson, 2011).

In much of Blascovich and colleagues' (2002) writing on this model they discuss classic work by Goffman (1956), in particular the notion of a non-person – a being who is not necessarily a performer nor an audience member, but someone whose presence places some restrictions on the behavior of those who are fully present. Goffman (1956) describes particular roles such as cab drivers and elevator operators and argues that "there seems to be uncertainty on both sides of the relationship as to what kind of intimacies are permissible in the presence of the non-person" (pp. 95). Indeed, this uncertainty of how social interaction unfolds is an apt description of social VR which can include avatars (of both strangers and familiar people) and embodied agents, powered by algorithms within the VE. Moreover, this same concept of a non-person likely also applies to other physical people around a VR user, who can only sporadically see or hear those other people given they are largely occluded by the head-mounted display.

In the present paper, we instantiate Blascovich and colleagues' (2002) social influence model to examine the presence of other people as a contextual factor, which we predict will have influences on some of the psychological mechanisms discussed above. In what follows, we review past literature on the types of behavioral patterns that emerge from social interactions, and how the presence of others in both the virtual and physical world affects such outcomes. Then, we introduce two field experiments that examine four of the five factors of the social influence model to understand how the presence of virtual and physical people contextualize and influence group dynamics.

Nonverbal Behaviors in Social Contexts

Nonverbal behaviors have frequently been investigated by researchers as reliable indicators of social outcomes. In both virtual and physical world dyadic and small group interactions, people express their attitudes through behaviors such as proxemics (i.e., interpersonal distance, or the amount of space an individual puts in between themselves and others), gaze, posture, touch, and facial expressions (Bailenson, Blascovich, Beall, & Loomis, 2001; Burgoon & Le Poire, 1999; Heisler & Friedman, 2012; Mehrabian, 1969; Miller, DeVeaux, Han, Ram, & Bailenson, 2023). Moreover, nonverbal behavior in immersive VE-based studies have been suggested to be a more sensitive measure of influence of virtual beings than self-report measures (Bailenson, Aharoni, Beall, Guadagno, Dimov, & Blascovich, 2004).

Researchers frequently rely on proxemics as an indicator of social outcomes such as comfort, with greater interpersonal distance signaling negative evaluations of the social other and less friendliness (Argyle, 1988; Yaremych & Persky, 2019). Moreover, proxemics have also shown to be reflective of phenomena such as ingroup/outgroup behaviors, with participants standing closer together if others were in the same type of group (e.g., ethnicity, Menshikova, Saveleva, & Zinchenko, 2018; gender and Hatami, Sharifian, Noorollahi, & Fathipour, 2020). Beyond these high-level social factors, there are other factors that contribute to how proxemic patterns merge. For example, crowdedness has been shown to affect interpersonal distance in VR, such that when there are more subgroups in a virtual room, people's comfortable interpersonal distance is reduced (Han, Wang, & Kuai, 2022). This suggests that people adjust their proxemics and are willing to accept closer interpersonal distances if there is greater social crowding. Together, these research point toward the idea that unique proxemic patterns arise in the presence of social others, and that social and physical proximity regulate these patterns.

In addition to proxemics, other relevant nonverbal behavioral indicators include eye gaze. Eyes are arguably one of the most critical facial features individuals rely on for social cues, such as attention, engagement, and directing attention (Brennan, Chen, Dickinson, Neider, & Zelinsky, 2008; Mason, Tatkow, & Macrae, 2005; Neider, Chen, Dickinson, Brennan, & Zelinsky, 2010). Researchers have further operationalized this behavior, finding evidence that the amount of gaze has also been tied with level of liking, with increased gaze suggesting greater degree of liking (Mehrabian, 1968). Furthermore, it has been shown that individuals demonstrate preferential gaze to ingroup members than to outgroup members. In social psychology research, ingroups have been shown to form on a variety of basis of similarity, ranging from demographic attributes to shared activities to preferences. Moreover, ingroup members influence social behavior to a greater extent when the group is stable and impermeable (i.e., difficult to gain membership)

(Triandis, 1989). There is evidence that participants attend to ingroup members' eyes more than they did to outgroup members (Kawakami et al., 2014). This pattern shows up not only in naturally formed ingroup/outgroup categories such as race, but also in experimentally created artificial categories. This suggests that more gaze is attended to individuals who are members of the same group, and that the definition of these groups can emerge both naturally and artificially.

Presence of Other Virtual Beings

Social VR platforms such as VRChat, RecRoom, and Horizon are spaces designed to encourage social interactions. Members are encouraged to collaborate, play games, and bond with one another. Many of the spaces within these platforms are public, meaning multiple people are present in the same environment at the same time. Whether an individual is by themselves or with others, they can see, hear, and feel the presence of others. It has been shown that mere virtual presence of another being, be it human- or computer-controlled, can foster social reactions (Liszio, Emmerich, & Masuch, 2017; Rickenberg & Reeves, 2000). Furthermore, there have been efforts to enhance social atmosphere through means such as populating the background with autonomous crowds conversing in groups (Ennis & O'Sullivan, 2012), simulating realistic crowds with basic social gestures (Kyriakou, Pan, & Chrysanthou, 2016), or social priming users through exposing them to conversations between virtual agents (Daher, Kim, Lee, Schubert, Bruder, Bailenson, & Welch, 2017). When Blascovich and colleagues (2002) created the social influence model in VR, they specified *theory of mind* as a continuous factor – virtual humans may be agents or avatars technologically, but how people interact with each type is much more nuanced and variable.

Several studies have investigated how social influence manifests, and how the five factors mediate and moderate outcomes (for reviews, see Felnhofer, Knaust, Weiss, Goinska, Mayer, & Kothgassner, 2023 and Fox, Ahn, Janssen, Yeykelis, Segovia, & Bailenson, 2014). For instance, a study found that people were more efficient and engaged in tasks when there was another avatar present in the VE (Fribourg, Argelaguet, Hoyet, & Lécuyer, 2018). Another study found that walking together with an avatar or agent influenced risk behavior while crossing traffic on a virtual road (Jiang, O'Neal, Rahimian, Yon, Plumert, & Kearney, 2016).

Similarly, Williamson and colleagues (2021) investigated social influence through the settings in which they occurred by analyzing how people arranged themselves in various contexts during a VR workshop, such as small breakouts and a keynote session. Results showed that participants formed more cohesive small groups in breakout rooms, where the next nearest neighbor was within their personal or social distance. Oppositely, during the keynote session, participants formed less cohesive groups, where the next nearest neighbor was further away. Furthermore, during the breakout sessions, participants could make easier sense of social cues and have conversations. The circular nature of these smaller sessions allowed them to identify the speaker more easily. This suggests that not all social interactions are the same: those occurring in private spaces look different from those that take place in shared public spaces. Overall, these studies point toward a similar direction: the presence of other virtual beings influences both low- and high- level behaviors.

Presence of Other Physical Beings

Within VR, multiple factors can affect the way people interact with one another. These factors include contextual factors such as noise or environmental distractions, intrapersonal factors such as verbal and nonverbal behavioral cues, and intrapersonal factors such as motivational or demographic characteristics (Swinth & Blascovich, 2002). One factor to consider during VR interactions is what occurs *outside* of the VE. The physical aspect of social interactions is a critical one, as we process sensory cues that are specific and unique to social behaviors (Chen & Hong, 2018). The mere physical presence of others has been shown to lead to greater social mindfulness (Van Doesum, Karremans, Fikke, de Lange, & Van Lange, 2018), diminish autonomic responses to aversive events (Qi et al., 2020), reduce stress reactivity (Goldring, Pinelli, Bolger, & Higgins, 2022), and increase risk-taking behaviors by providing a sense of security (Chou & Nordgren, 2017). From a higher-level perspective, physical proximity has shown to stimulate collaboration, engage in conversation, and signal intent by allowing individuals to assess each other's availability for communication. Oppositely, the lack of physical co-presence may lead to asymmetric available information, causing difficulties in awareness and initiating important conversations (Kraut, Fussell, Brennan, & Siegel, 2002).

More recently, researchers have found that phenomena such as social inhibition/facilitation occur within VR as well, as virtual beings have been shown to trigger social reactions (Blascovich et al., 2002; Wienrich, Gross, Kretschmer, & Müller-Plath, 2018; Zanbaka, Ulinski, Goolkasian, & Hodges, 2007). Social inhibition/facilitation is a classic phenomenon within the social psychology discipline that refers to how the physical presence of another inhibits performance (Triplett, 1898). In other words, people regulate or reduce their behavior when they are around people, compared to when they are alone. The presence of others increases arousal and enhances drive, which leads to faster dominant responses that are well-learned or automatically executed. As a result, the presence of others can facilitate performance when a task is familiar (i.e., social facilitation) and hinder it when a task is novel (i.e., social inhibition) (Zajonc, 1965).

However, there is a limited amount of research that considers the physical location of the others. How does being in physical isolation, or sharing the same space where interactants can see, hear, feel, and breathe the physical presence of others, influence virtual interactions? Terrier and colleagues (2020) investigated the impact of social inhibition in VR while an audience was physically present or remotely located. Participants engaged in tasks either alone, in the same virtual and physical environment with an audience, or in the same virtual but different physical environment with an audience. Results showed that participants' performance improved more slowly when there was a virtual audience, compared to when they were alone, and even more slowly when this virtual audience was physically separated. It was suggested that this could be due to a weaker perception of others compared to those who are physically together. Moreover, social inhibition occurred when participants had an audience. Interestingly, physically separated audiences seemed to affect social inhibition more strongly, with participants being more influenced when the audience was not physically present, despite the audience being less directly perceived. However, it was also noted that the examiners were passive and did not cause any additional stress to the participants. One could argue that, here, the physical audience were closer to members of the background, or non-persons, whose presence had some social influence, though one not as salient as that of the virtual audience.

Beyond social inhibition, there are other behavioral changes caused by the physical presence of others. For example, Brignull and Rogers (2003) observed how groups of people socialized around physical, public interactive displays and highlighted that self-consciousness, social awkwardness, and embarrassment may be core reasons that inhibit people from engaging in certain public interactions. Interestingly, one suggestion to reduce social awkwardness was to allow individuals to participate remotely and anonymously. In the case of social VR, where remoteness and anonymity exist in some form, how people engage in these public virtual spaces becomes an interesting question. Overall, these studies point toward a similar direction: the physical presence of others during a virtual interaction has social influence.

Overview of Studies

In the current paper, we present two field experiments that broadly examine how the presence of others influences behavior. We use the model of social influence to frame our understanding of the variables at play.

In Study 1, our central research question is as follows: **how will being in a private space or a public space influence group interactions (R1)**? In most social VR platforms, many interactions occur in a public setting, in which users are surrounded by multiple other individuals and groups. Rarely are people in complete isolation or solely interacting with one or a few individuals at a time. Here, we consider the factors of *self-relevance* and *theory of mind*. First, individuals will be both directly interacting with their group members, and indirectly interacting with other people who share the same virtual space, thus taking on varying degrees of *self-relevance* in the roles that they play. The people in the background are intended to be similar to non-persons such that they are treated as if they are not there, yet their presence places restrictions (i.e., low sentience from the *theory of mind* factor). Given previous research, we predict that the virtual presence of other indirect interactants – or non-persons – will have social influence.

In Study 2, our central research question is as follows: **how will the physical presence of interactants influence virtual group interactions (R2)**? In the physical world, an important part of social interactions is the physical, Face-to-Face (FtF) aspect. However, many social interactions that take place in VR are done in physical separation. How does being able to physically feel, hear, and see the presence of others differ from the virtual counterpart? Here, we consider the physical *context* in which virtual interactions take place. Given previous research, we predict that the physical presence of others will have some social influence, though this influence will differ from that caused by virtual others.

Both studies were field experiments housed in a 10-week and 8-week course, respectively, about VR and its intersections with various disciplines. During each course, participants were provided with a VR headset, which they used to interact with one another in a social VR platform. The nature of each study being housed in a course allowed for naturalistic intervention of our variables of interest and unobtrusive measurement of behaviors (see Limitations and Future Directions for more details about the nature of the studies). Nonverbal behavior was measured by recording 18 degrees of freedom of movement from each participant (e.g., pitch, yaw, and roll of head and both hands). Together, both studies address two aspects of the social VR experience: the *virtual* and the *physical* social experience, and sheds light on the influence of being physically together or alone on group interactions.

Study 1: Virtual Context

Although these VR platforms may primarily serve a social purpose, not all social interactions that occur on these platforms are equal. Returning to the fourth factor of the social influence model, consider the relevance a given person plays in any interaction. According to this factor, the way people interact with others differs and depends on the degree of self-relevance in the interaction. To illustrate an example, a social interaction between a person asking another to press the elevator button has low self-relevance, whereas a social interaction between a person asking another for a loan has high self-relevance (Blascovich & Bailenson, 2011).

Study 1 examines the dynamics an individual has with their direct group members (i.e., direct interactants; more self-relevance) and non-group participants who share the same virtual space (i.e., non-direct interactants; less self-relevance; those who play the role of non-persons, or beings that are treated as if they are not there but whose presence places restrictions). In this study, small groups are placed in either a private environment where they can only see and hear one another, or a public environment, where they can see and hear multiple other groups interacting in the background. This study examines how, compared to a private setting, the presence of a virtual audience or a virtual crowd in a shared, public space influences the behaviors of its groups (R1).

Methods

Participants

Participants were students enrolled in a course offered by a private university. At the beginning of the course, students were invited to participate in an Institutional Review Board-approved (IRB) study of how various exposures to VR influenced their behavior. While all students who were part of the course took part in all the VR activities, only those who consented to participate in the study contributed data for analysis. Safeguards implemented to ensure privacy and consent included review both by the IRB and a second university ethics organization, and third-party oversight of the consent process and data collection, and recurring reminders that they were being recorded at the beginning of every session.

Of the 152 students who took part in the course, 104 consented to participate and provided usable data (i.e., instances where there were only one student present in a session or the incorrect VE was loaded were excluded). Participants (M = 45, F = 57, something else = 2) were between 18 and 59 years old (M = 21.6, SD = 6.01, $n_{18\sim20}$ = 54, $n_{21\sim23}$ = 44, $n_{24\sim59}$ = 5, declined to or did not respond = 1) and identified as Asian or Asian-American (n = 46), White (n = 19), Hispanic or Latinx (n = 13), African, African-American, or Black (n = 9), bi- or multiracial (n = 11), Middle Eastern (n = 3), Indigenous/Native American, Alaska Native, First Nations (n = 1), Native Hawaiian or other Pacific Island (n = 1), and declined to or did not respond (n = 1). This sample represents a demographic of people who may use VR (i.e., young adults).

VR Hardware and Software

Participants were provided with Oculus Quest 2 headsets (standalone head-mounted display with 1832 x 1920 resolution per eye, 104.00° horizontal FOV, 98.00° FOV, 90 Hz refresh rate, and six-degree-of-freedom inside-out head and hand tracking, 503g) and two hand controllers (126g) for use in their personal environment.

All sessions were hosted in ENGAGE, a collaborative social VR platform designed for education. Participants met inside ENGAGE using their VR headsets in a password-restricted room consisting of a large, empty hub space. During the second week of the course, participants were trained on how to use the ENGAGE interface using their headsets and navigate the VE.

All technical support and instructions were delivered remotely, over Zoom. All participants were instructed to record their group members within ENGAGE using the MyRecording feature, which are files that capture the scene as it took place, including the nonverbal behavior of 18 degrees of freedom of movement (e.g., pitch, yaw, and roll of head and both hands of each participant), audio data, and objects in 3D space.

Virtual Context: Private vs Public

At weeks 7 and 8 of the course, groups were randomly assigned to one or the other of two levels of social virtual context: *private* or *public*. In the private condition, participants met with only their own group members in the VE. A flat circular object was placed in the center of the room. Participants were instructed to move to a circle that has been placed on the floor, though they were not instructed to stand inside the circle or in a particular orientation (Figure 1). The participants were informed that the circle was to guide them to where they can meet with their group members.

In the public condition, four groups met in the same VE, but were standing in four separate regions of the VE, marked by flat circular objects placed in evenly spaced out locations of the room. Participants were not assigned a specific circle but were instructed to meet with their group members at one of the circles. The public VE had 3D spatialized audio (i.e., the direction from which sound is preserved), allowing participants to hear other group members clearly, and hear, but not make out the details of the conversations happening in the other groups.

Participants were randomly divided into 40 groups of 2-4 people ($M = 3.16$, $SD = 0.767$). In the second week, each group was assigned to the opposite condition, following an AB, BA crossover model (2 sessions per individual; $n_{private\_t1} = 32$, $n_{public\_t1} = 51$, $n_{private\_t2} = 51$, $n_{public\_t2} = 38$). All participants were physically located in their own personal space (e.g., dorm room, house).

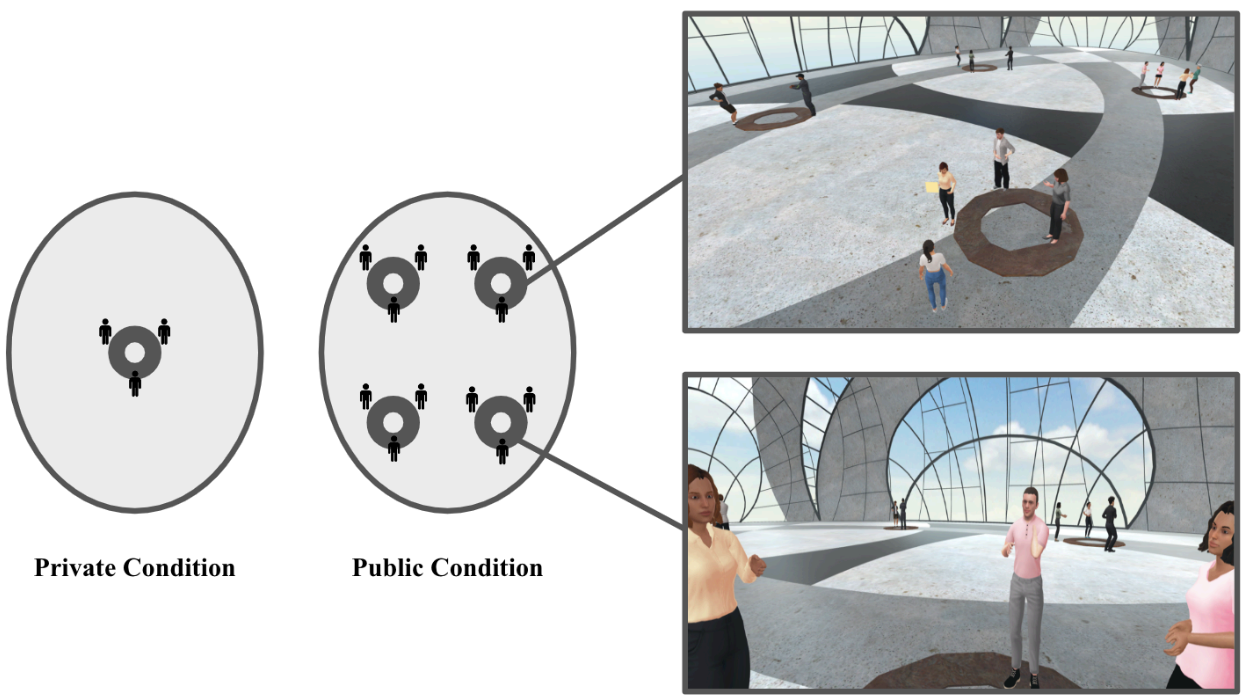

Figure 1. Bird's eye view layout of the VE in the private and public conditions. Circles represent the flat circular objects that the participants were instructed to meet at. The images on the right show examples of what the room configuration and discussions looked like.

Procedure

All participants met at the designated course time. The groups in the private condition met with their own group members in a private VE. The groups in the public condition met with their own group members in a public VE, which was shared synchronously with three other groups, resulting in four total groups. Each group met with their own group members in one of the marked areas of the VE, such that they were standing in a circular shape. In both conditions, participants reported that they were physically sitting down for most of the session (92.5% and 95.4% in the private and public conditions, respectively).

In the VE, participants had a discussion with their group members for approximately 20 minutes (M = 16.15, SD = 5.83). The discussion topic included questions related to the course topic for that week. Discussion topics are detailed in Table 1. Following each respective session, participants completed a questionnaire with outcome variables measuring various aspects of how they perceived their experience.

Table 1. Discussion prompt for each session

Session	Discussion Prompt
Session 1	Discussion questions were based on VR experiences students tried as a part of a prior course assignment. Question 1: What experiences did you try? Question 2: What details, images, or moments from the experiences struck you and stuck with you? Question 3: What images or details do you feel like missed the mark? Question 4: What aspects of your background, experience, and/or identity may have led to those reactions?
Session 2	Question 1: Do you think VR is an appropriate tool to help educate others about climate change? Consider the affordances and challenges of the medium. Question 2: Say you have the chance to bring anyone into a VR climate change experience that you created. *What would the experience be about?* (E.g., Threats to biodiversity, Global warming, Wildfires, Ocean Acidification, Climate Refugees, etc.) *Who would you bring?*

Can this individual influence others, as well? Why would a certain individual be motivated to make change if it doesn't benefit them or can harm them?
What would be your end goal?
Question 3: What are some other issues, outside of climate change, that you think would be worth creating a VR experience about?

Measures

Nonverbal behavioral metrics previously used to understand people's attitudes were selected to be analyzed, including interpersonal distance (i.e., proxemics) and mutual gaze. To do this, each participant's motion data was measured by recording 18 degrees of freedom of movement (yaw, pitch, and roll of head, left, and right hands) every one-thirtieth of a second (30 Hz). Instances where tracking data was lost (i.e., the distance between the head and hands positional vector was greater than 3 m) were filtered out. In the present analysis, we report measures that are proportional to time (e.g., speeds and percentages), as opposed to measures that are totaled over time, to account for discrepancies that may arise from differences in duration of sessions.

In addition to interpersonal distance and mutual gaze, we considered how fast participants were moving their head and hands. Returning to Blascovich and colleagues' (2002) model of social influence, consider the third factor, *response system level*. According to this factor, the location of the social influence threshold changes as the level of the behavioral response system changes. A distinction is made between low-level response systems, such as unconscious reflexes and actions, and high-level response systems, such as conscious and purposeful actions. Nonverbal behaviors, such as gestures and glances, are mainly automatic (Bailenson, 2018). In VR, however, in addition to these automatic behaviors, individuals can also use their joysticks to move their avatars. Here, we distinguish low- and high-level response systems through automatic and deliberate motion. More specifically, we distinguish what a participant is doing physically, and what a participant's avatar is doing virtually. Physical motion is defined as the motion performed in the physical world. This reflexive motion is best described as what Blascovich and colleagues refer to as an *automatic response*, as it represents how a participant is reflexively and instantaneously responding through bodily movements. We henceforth describe this variable as automatic motion.

Meanwhile, abstract motion is defined as the motion produced by the interface by implementing "smooth translating," "joystick rotating" and "teleporting." This motion is best described as what Blascovich and colleagues refer to as a deliberate response, as it represents conscious, purposeful movements that an individual decides to make. While the mappings of moving one's body physically in the room compared to intentionally hitting a button on a controller to move virtually are not perfect mappings onto automatic/deliberate responses as outlined by Blascovich and colleagues, the distinction is helpful in understanding how these outcome measures may differ by condition. We henceforth describe this variable as deliberate motion.

Average Speed Per Second

The average speed per second for automatic motion (i.e., a participant's physical movements) was operationalized by calculating the speeds of head, left, and right hands in a given moment in frame, which was multiplied by 30 to get the speed per second, and then averaged. There are a total of three automatic motion measures, all in units of meters per second. Meanwhile, deliberate motion (i.e., a participant's avatar's virtual movements) for each individual was operationalized as the speed of the avatar's root (i.e., center of their avatar), which was calculated using the same equation as in automatic motion.

While automatic and deliberate motion are reported in terms of speed, it may be helpful to also consider these measures as distance traveled in a given portion of time. Mathematically speaking, these measures are indistinguishable, but conceptually and phenomenologically, they are different. An increased average speed can be due to increased energy, longer teleporting events, or more teleporting events. Following the procedure by Han and colleagues (2023), for our deliberate motion measure, we did not look independently at movements made by "smooth translating" or "teleporting," as teleporting occurred less than 1.36% and 1.83% of the time during the private and public conditions, respectively.

Mutual gaze

Mutual gaze is the act of two individuals looking at one another. This measure was calculated for each individual as the percentage of time they had at least one group member within 15° of their center of HMD view, with the group member looking back at the individual, who was also within 15° of that group member's center of HMD view (see thresholding technique proposed by Miller, Sonalkar, Mabogunje, Leifer, & Bailenson, 2021). A threshold value of 15° was selected, as the angle between one's gaze and head direction is typically less than 15° (Foulsham, Walker, & Kingstone, 2011). Furthermore, the 15° threshold for mutual gaze has shown to yield consistent results to lower thresholds (5° and 10°; Wang, Miller, Queiroz, & Bailenson, 2024).

Interpersonal Distance

Interpersonal distance for each individual was calculated as the distance, in meters, that they stood from each member of their group, averaged across members of the group. The distance between each pair of participants was taken after filtering out the smallest 150 distance points (i.e., ~5 seconds), to account for behaviors that are not of interest that may have occurred at the beginning of each recording, such as participants entering the recording and their avatars spawning in the same starting location. Interpersonal distance was calculated based on head positions (for examples of similar procedures, see Bailenson, Blascovich, Beall, & Loomis, 2003; Han, DeVeaux, Hancock, Ram, Harari, & Bailenson, 2024; Wieser, Pauli, Grosseibl, Molzow, & Mühlberger, 2010). Note, interpersonal distance may look different using different body-part positions (i.e., distances based on head to head positions versus body-part to body-part positions), as head or body sizes are not being accounted for.

Data Analysis

We examined the relationship between our outcome variables and our independent variable, virtual context, using linear mixed-effects models that accommodate the nesting of repeated observations within subjects within groups. We additionally tested both 3-level (repeated measures within person within group) and 2-level (repeated measures within person) models and did not collapse to the 2nd level, as the group accounted for more than 10% of variance. Across outcomes, group-level variance accounted for between 16.03% and 74.2%, person-level variance accounted for between 0% and 37.6%, and session-specific variance for between 19.5% and 73.8% of total variance. Models with interactions were tested, but in no cases were the interaction terms significant. Thus, we report the more parsimonious models. Within the 3-level structure the outcome variables were modeled as a function of the independent variable and session (time) as fixed effects, and participant and group as random effects. Specifically, our equation is as follows:

$$outcome\ variable_{tig} = \beta_0 + \beta_1(Session_{tig}) + \beta_2(Virtual\ Context_{tig}) + u_{0g} + u_{0ig} + \epsilon_{tig}$$

(Equation 1).

Here, β_0 is the prototypical level of the outcome for participants who were in the private condition in the first session, β_{1i} indicates any order effects as systematic difference between the first and second sessions, β_{2i} indicates any virtual context effect as systematic difference between the private and public conditions, and u_{0g}, u_{0ig}, and ϵ_{tig} are unexplained group, individual, and session specific differences (residuals). Note, the subscripts *t* represent the session (time), *i* represent the individual, and *g* represent the group. Effect sizes are reported by both the marginal R^2 (R^2m), which is the amount of variance in the outcome variable explained by the fixed effects, and the conditional R^2 (R^2c), which is the amount of variance in the outcome variable explained by the fixed and random effects.

All models were fit to the data in R using the lme4 package (Bates, Mächler, Bolker, & Walker, 2015), with maximum likelihood estimation, incomplete data treated as missing at random, and statistical significance evaluated at alpha = 0.05. Conditional and marginal R^2 were calculated using the MuMIn package (Barton, 2009). Confidence intervals (CIs) for marginal R^2 were calculated using the r2glmm package (Jaeger, 2017) using the method suggested by Nakagawa and Schielzeth (2012). Figures were generated using the ggplot2 package (R Core Team, 2019; Wickham, 2016).

Results

Results from our examination of the outcome variables with virtual context are presented in Table 2. Descriptive statistics of each outcome variable are presented in Table 3.

Average Speed Per Second

Automatic Motion

Automatic motion average head speed was β_0 = 0.0316 m/s, $p < .001$ for participants when they were in the private condition. We did not find a main effect of session or virtual context on average speed of head ($\mathscr{X}^2$ (2) = 3.46, p = .178), such that they did not change across sessions, β_1 = 0.00323, p = .0794, or when participants were in the public condition, β_2 = -0.0000773, p = .966. Conditional and marginal R^2 for the model were R^2c = 0.6069, R^2m = 0.00921, CI (0.001, 0.079), respectively.

Additionally, we did not find a main effect of session or virtual context on automatic motion average speed of *left hand* or speed of *right hand* (all *p-values* > .4).

Deliberate Motion

Deliberate motion average speed was β_0 = 0.0639 m/s, $p < .005$ for participants when they were in the private condition. While there was no main effect of session on deliberate motion *root* speed, β_1 = -0.000586, p = .945, when participants were in the public condition, they moved their virtual bodies at a slower speed (M = 0.03, SD = 0.08), β_2 = -0.02011, $p < .05$, ($\mathscr{X}^2$ (2) =

6.10, $p < .05$), compared to when participants were in the private condition ($M = 0.07$, $SD = 0.13$). Conditional and marginal R^2 for the model were $R^2c = 0.80902$, $R^2m = 0.00840$, CI (0.001, 0.081), respectively (Figure 2). Results from our examination of average speed per second with virtual context are presented in Table 2.

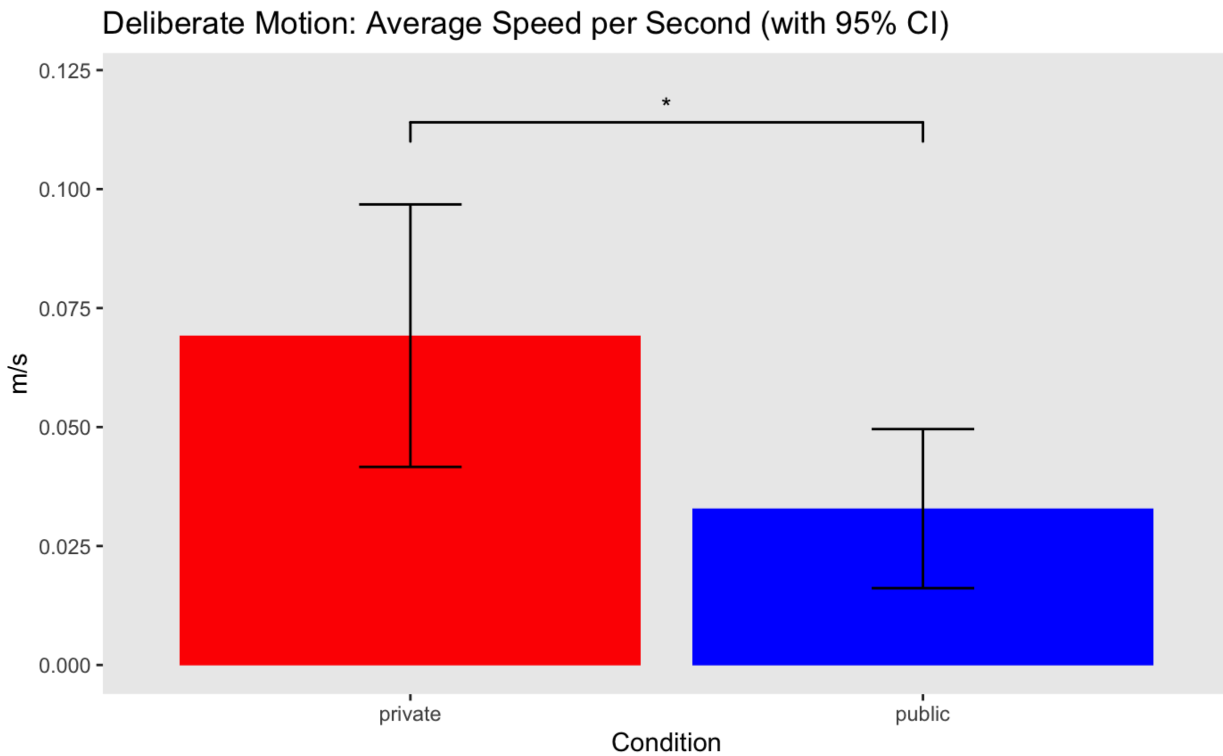

Figure 2. Average speed per second of deliberate motion root during the private and public conditions. * = $p < .05$, ** = $p < .01$, *** = $p < .001$.

Mutual Gaze

Mutual gaze was $\beta_0 = 0.10056$ percent, $p < .001$ for participants when they were in the private condition. We did not find a main effect of session or virtual context on mutual gaze ($\mathscr{X}^2$ (2) = 0.322, $p = .851$), such that they did not change across sessions, $\beta_1 = 0.00645$, $p = .636$, or when participants were in the private condition, $\beta_2 = 0.0054$, $p = .692$. Conditional and marginal R^2 for the model were $R^2c = 0.524$, $R^2m = 0.00102$, CI (0, 0.052), respectively. Results from our examination of mutual gaze with virtual context are presented in Table 2.

Interpersonal Distance

Interpersonal distance was $\beta_0 = 2.0082$ m, $p < .001$ for participants when they were in the private condition. While there was no main effect of session on interpersonal distance, $\beta_1 = 0.0136$, $p = .849$, when participants were in the public condition, their interpersonal distance between group members was smaller ($M = 1.81$, $SD = 0.77$), $\beta_2 = -0.238$, $p < .01$, ($\mathscr{X}^2$ (2) = 11.8, $p < .005$), compared to when participants were in the private condition ($M = 2.00$, $SD = 0.95$). Conditional and marginal R^2 for the model were $R^2c = 0.764$, $R^2m = 0.0189$, CI (0.003, 0.109), respectively (Figure 3). Results from our examination of interpersonal distance with virtual context are presented in Table 2.

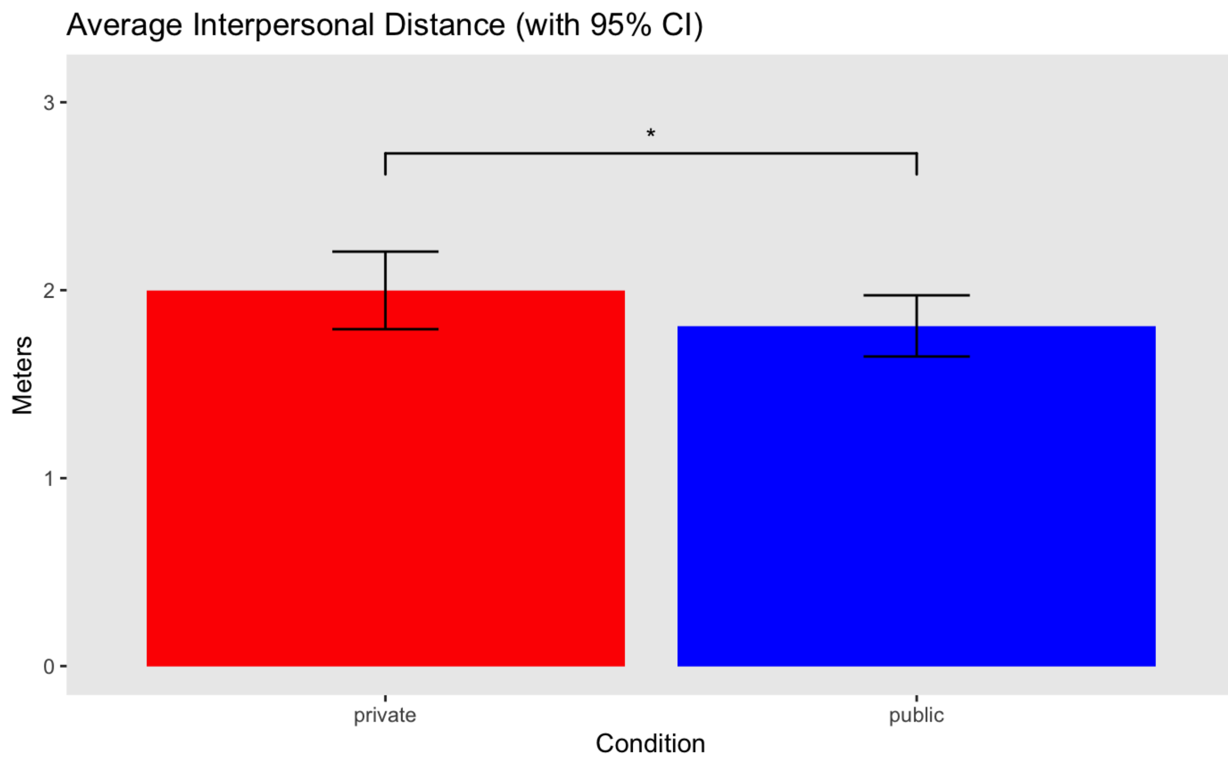

Figure 3. Interpersonal distance between members of a group during the private and public conditions. * = $p < .05$, ** = $p < .01$, *** = $p < .001$.

Discussion

The present field experiment examined how being surrounded by others in the virtual world, or, how being in a public space with multiple other groups, affects individuals' experience with their own group members. Small groups were placed in marked areas of VEs either by themselves (private) or with four other groups (public) and engaged in discussions with their group members.

Results showed that physically, there were no differences in how fast participants were moving their body parts. However, virtually, participants moved more slowly when they were in the public condition. In other words, participants were automatically moving their body parts similarly in both conditions but were deliberately moving more slowly within the VE when they were surrounded by multiple others.

This outcome could be due to several reasons: first, there may have been some social inhibition effect. How social inhibition takes form depends on whether a person is engaging in a novel or familiar task. If the task is novel, the presence of others can hinder performance (Zajonc, 1965). Both sessions of the study occurred during the 7th and 8th weeks of the course. Prior to the study, participants took part in other discussions that were structured similarly to that of the private condition such that they were alone with their group members. However, in the public condition session, being surrounded by four other groups may have introduced a novel situation, inducing some type of social inhibition effect. While the participants were not engaging in a performance-based task, they were discussing different topics with their group members, and the social inhibition may have taken effect on their performed bodily actions.

Another potential reasoning pulls from research on how people behave around public displays. In the physical world, people tend to refrain from engaging in certain public interactions due to self-consciousness, social awkwardness, and embarrassment (Brignull & Rogers, 2003). Similarly, in a public VE the presence of a virtual audience may have induced similar reactions. Participants may have noticed the presence of an audience (i.e., the other four groups) watching and felt more self-conscious. A desire to not want to draw attention may have caused them to move their body more slowly and perhaps more in control, rather than more quickly and frantically.

Results also showed that participants were, on average, standing closer to their group members when they were in the public condition. One potential reason here is that the presence of more groups in the same virtual space may have caused a sense of greater social crowding, and participants were willing to accept closer interpersonal distance (Han et al., 2022). This does not necessarily mean that participants felt closer to their group members. Results showed that the public condition did not yield more mutual gaze. However, this smaller interpersonal distance may suggest that they were willing to accommodate and adjust to being in a different social context. Qualitative results from the open-ended questions collected after each experience shed some light on this finding. One participant noted that, because of the spatialized sound feature during the public session, they found themselves more "inclined to turn towards the person who was talking when the noise was coming from the direction they were in." Furthermore, another participant commented that their group was "a little more shy and quiet" during the public condition, and wondered if they may have been quieter because of the spatialized sound.

Study 2: Physical Context

Whereas Study 1 focuses on the social virtual context, examining the effects of the virtual audience, Study 2 focuses on the social physical context. Returning to the fifth factor of the social influence model, consider the contexts in which social interactions take place. According to this factor, people's behavior depends on where they are. For example, people change how loudly they speak or what words they choose to use depending on whether they are in a quiet library or a loud cafeteria, as the norms and expectations associated with those contexts differ (Blascovich & Bailenson, 2011). This is in line with ideas from classic social psychology, such as Goffman's (1956) position that people wear different masks for different social interactions, playing the role best suited for a particular situation and audience. How people behave in a large, crowded auditorium will be different from how they behave in a smaller, private room such as their bedrooms.

Study 2 specifically examines how the physical presence and proximity of other beings influence group interactions (R2). Although the nature of social VR is to connect individuals who may be physically separated, it may also be used in other contexts (i.e., classrooms, workplaces) in which the physical separation may not necessarily occur. Much like in Study 1 in which we referred to the factor of *theory of mind*, Study 2 examines the presence of physical non-persons, who are beings that are not necessarily present in the direct interaction (i.e., in this case, the interactions within the VE) but whose presence is still clear and places some restriction on one's behavior. In Study 2, we investigate the outcomes of two groups meeting in a VE while they are in either a shared physical environment or separated physical environments.

Methods

Participants

Participants were students enrolled in a course offered by a private university. At the beginning of the course, students were invited to participate in an Institutional Review Board-approved (IRB) study of how various exposures to VR influenced their behavior. For children under 18, the study was described to them in detail and ensured that they were aware of what they were agreeing to do. While all students who were part of the course took part in all the VR activities, only those who consented or assented were included for data analysis. Safeguards implemented to ensure privacy and consent included review both by the IRB and a second university ethics organization, and third-party oversight of the consent process and data collection.

Of the 99 students who took part in the course, 77 consented to participate in the study. The 61 participants (M = 33, F = 25, something else = 2, declined to or did not respond = 1) who provided usable data were between 16 and 34 years old ($M = 19.2$, $SD = 3.57$, $n_{16\sim19} = 33$, $n_{20\sim23} = 22$, $n_{24\sim34} = 5$, declined to or did not respond = 1) and identified as Asian or Asian-American ($n = 30$), White ($n = 15$), Hispanic or Latinx ($n = 9$), African, African-American, or Black ($n = 3$), a racial group not listed ($n = 1$), Middle Eastern ($n = 1$), and declined to or did not respond ($n = 2$). This sample represents a demographic of people who may use VR (i.e., young adults).

VR Hardware and Software

As in Study 1, participants were provided with Oculus Quest 2 headsets. All sessions were hosted in ENGAGE in a large, empty hub space. During the second week of the course, participants were trained on how to use the ENGAGE interface using their headsets and navigate the VE. All sessions were recorded on two separate computers, which captured nonverbal behavior of 18 degrees of freedom of movement (e.g., pitch, yaw, and roll of head and both hands of each participant) and audio data.

Physical Context: In-person vs Remote

At week 3 of the course, participants were assigned to a condition of our independent variable, physical context. There were two conditions: *in-person* or *remote*. In the in-person condition, participants met in a lecture hall that could seat around 500 people and were spaced apart to help with audio overlap (Figure 4). In the remote condition, participants met on Zoom, a video conferencing platform. Participants were randomly divided into two groups. Each group was assigned at random to one of two conditions: in-person ($n = 30$) or remote ($n = 32$).

Figure 4. The physical room that participants were in during the in-person condition. Illustrative avatars were added to show the rough seating arrangements.

Procedure

Session times were staggered in time. Participants in the in-person condition met first in a large lecture hall at a designated time. In that location, participants used their headsets to join their group in ENGAGE in a large gathering VE. Participants were allowed to choose their seats but were asked to sit with enough space between one another to allow for movement and prevent audio overlap. Most participants (93.3%) reported that they were physically sitting down for most of the session.

In the VE, participants were led by the course instructor, who was also in ENGAGE via VR, and engaged in different physical activities and discussion for approximately 30 minutes. There was a 5-minute activity in which the instructor yelled a number, and the participants were instructed to find partners and form groups of that number. Following the physical activity, participants were instructed to form a big circle. The instructor then posed different discussion questions and asked participants to step into the middle of the circle to respond to the question. Course and research personnel were physically present in the lecture room to provide technical support. All instructions were delivered in-person and moved to VR once participants were inside the VE.

Following the in-person session, the participants in the remote condition first met on Zoom, a video conferencing platform, where they were delivered instructions on setup. Almost half of the participants (45.2%) reported that they were physically sitting down for most of the session, while 25.8% reported that they were physically standing for most of the session.

After, the participants moved into ENGAGE, to an identical VE that was used in the in-person session. The remote participants took part in the same activities as the in-person participants. All instructions were delivered over Zoom and moved to VR once participants were inside the VE.

Course and research personnel were remotely present on the Zoom call to provide technical support. Following each respective session, participants completed a questionnaire with outcome variables measuring various aspects of how they perceived their experience.

Measures

The measures were the same as in Study 1. One outlier was excluded from the deliberate motion average speed per second measure, as their root speed was 5.29 standard deviations above the mean. As in Study 1, in our deliberate motion root speed measure, we did not look independently at movements made by "smooth translating" or "teleporting," as teleporting occurred less than 2.13% and 2.81% of the time during the in-person and remote conditions, respectively.

Data Analysis

We used one-way ANOVA to model our nonverbal behavioral outcome variables as a function of our independent variable, physical context. Shapiro-Wilk test was used to test the normality of the data distribution. Levene's test was used to examine the homogeneity of variance. If the distributions were not normal or the variances were not homogeneous, an Aligned Rank Transformation (ART) was applied, a nonparametric approach that does not require distribution normality (Wobbrock, Findlater, Gergle, & Higgins, 2011).

All models were fit to the data in R using the stats or ARTool package (R Core Team 2019; Kay, Elkin, Higgins, & Wobbrock, 2021). Statistical significance was evaluated at alpha = 0.05. Levene's test was employed using the car package (Fox & Weisberg, 2019). Figures were generated using the ggplot2 package (R Core Team, 2019; Wickham, 2016).

Results

Descriptive statistics of each outcome variable are presented in Table 4.

Average Speed Per Second

Automatic Motion

We found a main effect of physical context on automatic motion average *head* speed, $F(1,59) = 4.64$, $p < .05$, $\eta^2 = 0.07$, such that participants in the in-person condition physically moved their *head* at a slower speed than those in the remote condition. We found a main effect of physical context on average *left hand* speed, $F(1,59) = 18.4$, $p < .001$, $\eta^2 = 0.24$, such that participants in the in-person condition physically moved their *left hand* at a slower speed than those in the remote condition. There was no statistically significant difference in average *right hand* speed between the in-person and remote conditions, $F(1,59) = 3.98$, $p = .05063$, $\eta^2 = 0.06$ (Figure 5).

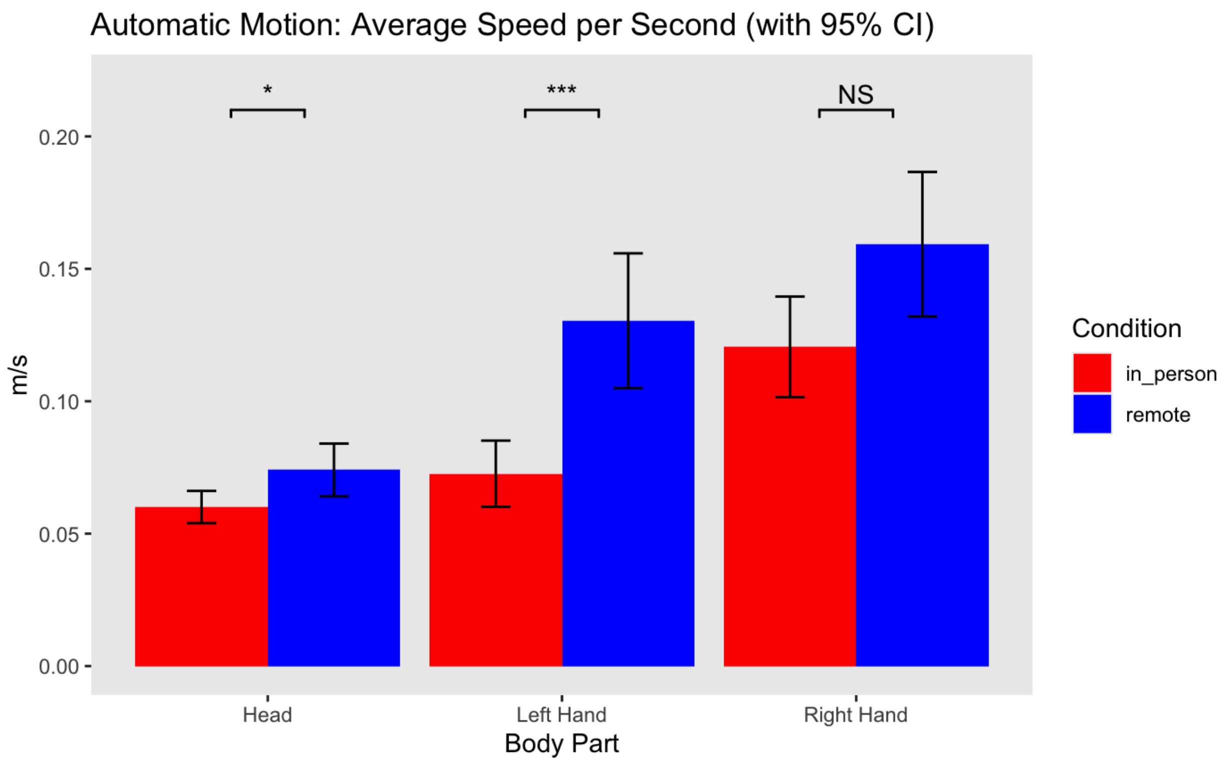

Figure 5. Average speed per second of automatic motion head, left, and right hands during the in-person and remote conditions. Left and right hands values represent motion as tracked, separate from and not relative to the head. * = $p < .05$, ** = $p < .01$, *** = $p < .001$, NS = Not Significant.

Deliberate Motion

We found a main effect of physical context on deliberate motion average root speed, F(1,58) = 24.5, $p < .001$, $\eta^2 = 0.30$, such that when participants were in the in-person condition, within the VE they moved at a faster speed than those in the remote condition (Figure 6).

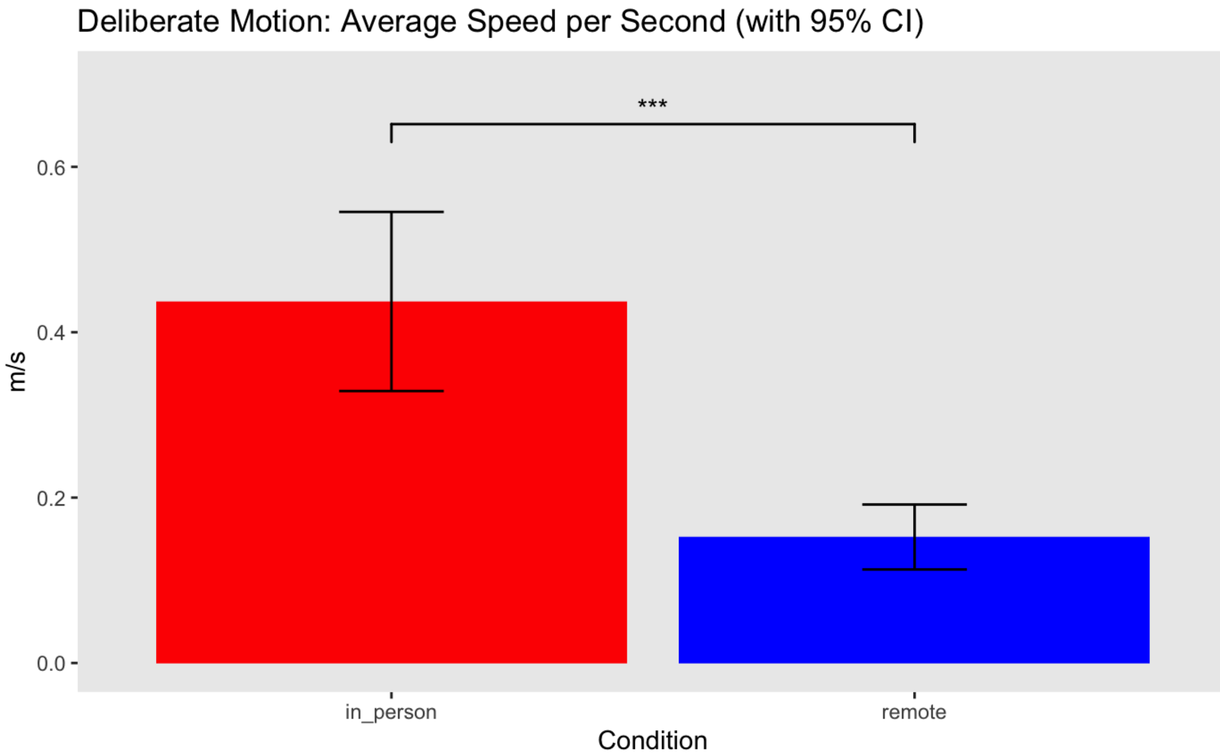

Figure 6. Average speed per second of deliberate motion root during the in-person and remote conditions. * = $p < .05$, ** = $p < .01$, *** = $p < .001$.

Mutual Gaze

We found a main effect of physical context on mutual gaze, $F(1,59) = 5.29$, $p < .05$, $\eta^2 = 0.08$, such that there was greater mutual gaze amongst participants in the remote condition than those in the in-person condition (Figure 7).

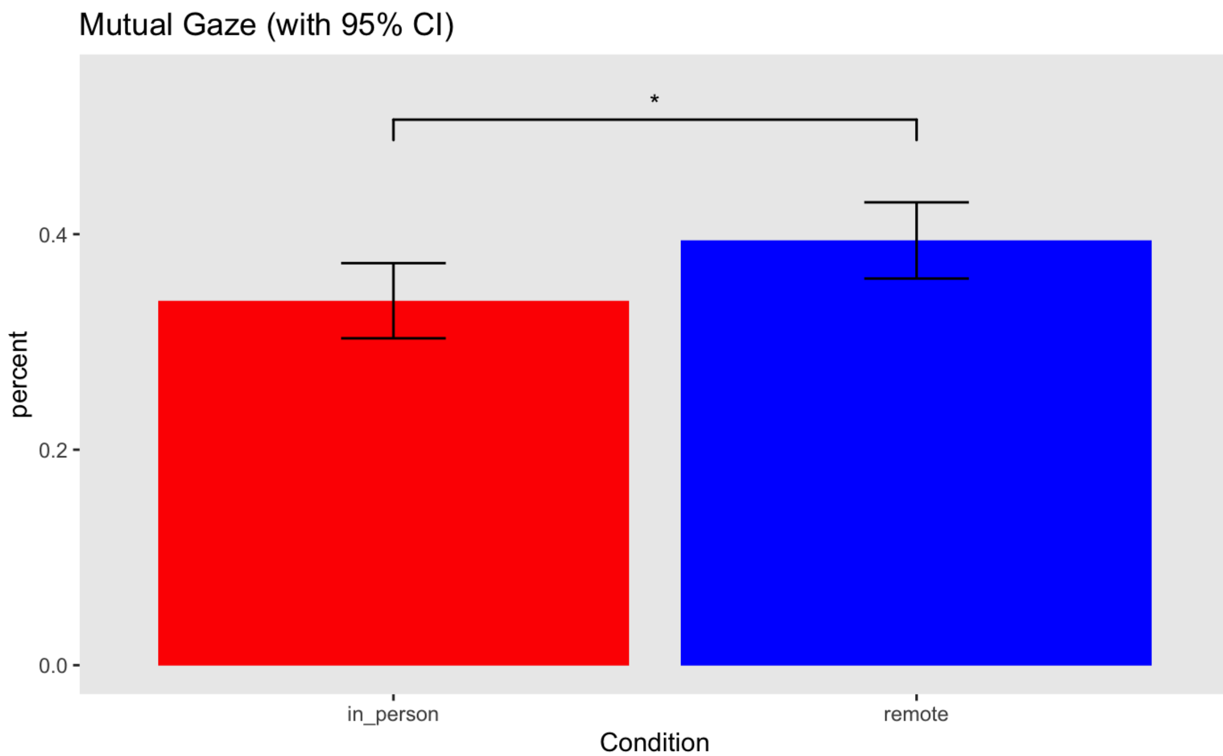

Figure 7. Average mutual gaze, in percent, between participants during the in-person and remote conditions. * = $p < .05$, ** = $p < .01$, *** = $p < .001$.

Interpersonal Distance

There was no statistically significant difference in interpersonal distance between the in-person and remote conditions, $F(1,59) = 1.99$, $p = .164$, $\eta^2 = 0.03$.

Discussion

The present field experiment examined how being physically located in the same or separate environment with others during a virtual interaction affects individuals' experiences with their group members. One group was in a shared physical environment and the other group was in separated physical environments. Within the VE, each group engaged in various activities and discussions with their group members.

Results showed that physically, participants who were in a shared physical environment moved their head and left hand more slowly than those who were physically remote. However, within the VE, participants moved faster when they were in the same physical space. In other words, participants who were physically together were moving their physical bodies more slowly but were deliberately moving their virtual bodies faster.

This outcome could be due to a social inhibition effect, as in Study 1. Social inhibition occurs when participants have an audience, both virtual and physical (Terrier et al., 2020). In the present study, the other beings in both conditions were not passive onlookers, but other interactants. Here, social inhibition in the physical world (i.e., the social influence exerted from the physical presence of others) may have been stronger than that of the virtual others. Participants' movement and performance may have been inhibited more strongly by those who were sitting physically close to them, manifesting in slower head and left hand movements. More specifically for left hand movements, this result may suggest that participants engaged less with the functionalities of the platform (e.g., opening up the tablet or finding the unmute button), much of which are accessed using the left hand controller.

Furthermore, participants may have taken extra caution to not accidentally hit their neighbor with their controller. Participants may have felt and heard others waving their hands and constrained themselves. Instead, participants may have made up for their lack of physical movement through virtual movement, which is aligned with the idea that the social influence of physical others was greater than that of virtual others. That being said, this inhibition of physical motion may have arisen from practical reasons, rather than psychological ones. The fixed furniture in the auditorium may have inhibited the automatic, physical movements while those in the remote condition may have had more mobility. From a practical standpoint, most in-person, shared spaces have constraints placed by the environment that are not found in remote spaces where there is a single occupant. These include having more limitations in space to move around in (e.g., there are more chairs, tables, furniture in such shared spaces) and concern of bumping into others. We point out this practical facet, both to highlight this as a potential confound, but one that is an inherent characteristic of most in-person spaces. We further discuss this in the Limitations section below.

Furthermore, results showed that there was more mutual gaze among interactants who were in separated physical environments than those who were in the same physical space. Participants in the in-person condition, unlike those that were in the remote condition, were able to see, hear, and feel each other at all times (i.e., even when they were virtually muted, the sounds in the physical room were not. Moreover, participants could see each other when putting on and taking off their headsets). This may have led to certain social senses and experiences being missed in the remote condition, leading to an increased need (i.e., through more mutual gaze) to make up for the social aspect within the VE.

General Discussion

Summary of Results

In the present paper, we used the model of social influence to understand how different factors govern the way people engage with others in VR. Specifically, we used the factors *theory of mind*, *self-relevance*, and *context* to frame our independent variables, virtual and physical context. Additionally, we used *response system level* to divide the type of motion responses, our dependent variables, into automatic and deliberate motion.

In Study 1, we looked at how people's behaviors change when in a private space or a public space (R1), as they directly interacted with group members (i.e., examining the *self-relevance* of the participant) or indirectly interacted with non-group members – or non-persons (i.e., examining *theory of mind* of the background avatars, or beings that are treated as if they are not there, yet their presence places restrictions). Small groups were placed in VEs either by themselves (private) or with four other groups (public) and engaged in discussions with their group members. Results showed that there were no differences in how fast or how much participants were physically moving their body parts. However, participants moved more slowly and deliberately within the VE when they were in the public condition. Lastly, participants were, on average, standing closer to their other group members when they were in the public condition.

In Study 2, we investigated the physical location of participants (i.e., the physical context in which the social interactions took place) (R2) as they virtually interacted with each other in the same or separated physical spaces. Two groups were placed in VEs either in a shared physical environment or in separated physical environments. Within the VE, members of the group engaged in various activities and discussions with their group members. Results showed that participants who were in a shared physical environment moved their head and left hand more slowly than those who were in separated physical environments. Furthermore, participants who were physically together moved their virtual bodies faster than those who were remote. Lastly, results showed that there was more mutual gaze among interactants who were physically separate than those who were together.

Limitations and Future Directions

There are several limitations to both Studies 1 and 2. First, both studies were field experiments, which serves as both a strength and a limitation. Although field experiments allow researchers to implement interventions and measure outcomes in naturalistic settings that would otherwise be challenging to implement in laboratory settings, there are constraints in how much control the researchers have on sample size, external conditions, and potential confounds. There were certain factors, such as what week of the course the studies were conducted, which may have contributed to how comfortable the students were with VR and each other, or having a large number of participants (i.e., Study 2, in-person session) relying on the same WiFi network to connect to the social VR platform, which may have caused potential latency issues that were outside of the researcher's control. Such factors may have played a role and should be further investigated separately in future research.

Furthermore, our sample was high school and college students and students learning about the medium of VR, which makes them a very particular sample. In this vein, the participant population was limited in terms of racial and age representation. Certain demographic factors, such as cultural differences, which have shown to play a role in how people socially interact with one another, were not examined in this study. An investigation into how cultural norms and expectations shape behaviors in this context is necessary in future research. In addition, we relied dominantly on one type of HMD, the Oculus Quest 2, and one software, ENGAGE. There may have been hardware constraints unique to this specific HMD and its controllers (e.g., latency), as well as software (e.g., fidelity of avatars, behavioral realism) constraints unique to ENGAGE that may have introduced and shaped behavioral outcomes. In particular, factors such as behavioral realism have shown to play a critical role in quality of communication (Garau et al., 2003). We note that future research could benefit from both stimulus sampling (Reeves, Yeykelis, & Cummings, 2015) and examining how these outcomes pan out across different hardware and software.

Second, in this vein, there were also environmental factors pertaining to the physical environments of the students during the sessions, such as external distractions, space to move around, and seating arrangement. Specifically in Study 2, we used a large auditorium for participants to meet in the in-person condition. This room was a lecture-style environment with rows of seats and small tables. These seats were not adjustable and were all facing in the same direction towards the front of the auditorium. Although we did not collect any data on the spaces that the participants in the remote condition used – or across both studies, in general – the seat options were most likely more diverse and provided more degrees of freedom of movement (i.e., rigid chairs, spinning chairs, the bed, the floor). Additionally, in our present study, we instructed participants to sit with enough space between one another to allow for movement and prevent audio overlap. However, several participants moved around throughout to be closer to other members or help one another, or further away to have better audio quality. In the future, accounting for the type of chairs, environment, and seating arrangements will allow for a more controlled experiment and address any confounds present in the present study.

Third, in Study 1, we utilized spatialized sound in the public condition. As iterated above, spatialized sound allowed for participants to hear other group members clearly, and hear, but not make out the details of the conversations happening in the other groups. Spatialized sound was not turned on during the private condition as they were both equal in volume when in a private setting. However, given the qualitative comments that referred to participants leaning in closer to hear their group members, it is possible that spatialized audio contributed to creating a unique social dynamic that is separate from the constructs were interested in observing. One potential way to address this in future research is to incorporate spatialized sound in the private condition as well, to create the same audial environment in both conditions and ensure that the spatialized nature of the audio was not contributing to the outcomes.

Fourth, in Study 2, even in moments when all participants in the in-person condition were muted in-world (i.e., when instructions were being delivered), they were able to hear one another. Casual chatter and conversations between participants were naturally a part of the physical environment. However, this was not translated in the remote condition. When participants were asked to be muted, they were able to see, but not hear what others were doing or saying. This inevitable byproduct caused a discrepancy that was not controllable or accounted for in the analysis. Although Study 2 focuses on the physical presence of others, rather than the audio aspect, there is room for future research on how the auditory environment (e.g., being able to hear other participants) contributes to the virtual experience.

Fifth, in the present research we use Blascovich and colleagues' (2002) model of social influence, in particular the response system level factor, to map the different ways an individual could move both inside and outside of VR – virtual and physical behaviors – onto automatic and deliberate motion. While this distinction was done to make sense of how participants were moving their physical and virtual bodies differently, this distinction was done ad-hoc. Potential future research can work towards establishing more comprehensive motion categories that are generalizable and applicable to virtual immersive experiences.

In a similar vein, there are a plethora of other behaviors that we did not look at for the scope of this paper that may provide a more nuanced understanding of nonverbal communication. While we focused on behaviors that have previously been used to understand people's attitudes (e.g., comfort, attention), future works should investigate other nonverbal behaviors, such as rotations and gestures.

Lastly, in the present research, the results were drawn from only one or two sessions. In other words, both studies were temporally underpowered. Past research has shown the critical role of time in how people's attitudes and nonverbal behaviors in VEs evolve with more use and familiarity with VR (e.g., Bailenson & Yee, 2006; Han et al., 2023). Results drawn from a single session may paint a noisy, inaccurate picture. New patterns may have emerged as participants grew more accustomed to these different contexts. This raises the question of how these outcomes hold or evolve with time.

Implications

Virtual Context

One takeaway from Study 1 is that not all social interactions are equal. This present research underscores the role of non-persons, whose presence is seemingly trivial but powerful. As the social influence model lays out, there are multiple factors that contribute to how much social influence is induced. Interactions that take place in private spaces look quite different from those that take place in public spaces, such that people's behaviors are adjusted depending on who was in the virtual background.

Although having non-persons – which can take the form of virtual agents and simulated conversing crowds – may help foster a social atmosphere, there should be careful consideration on how shared spaces are designed. Questions such as: how many groups is too much and leads to discomfort? How can large public spaces feel just as intimate as private spaces? How will audio be configured such that there is both a social, but private, aspect to the VE? should be considered.

Furthermore, given that VR induces high presence and embodiment, social VR may not provide that remoteness or anonymity that digital platforms provide to help people feel less self-conscious and embarrassed in public spaces. New social norms and expectations may arise that are driven by how public these spaces are.

Physical Context

Although the power of social VR lies largely in its ability to connect people from anywhere, at times, this component is not necessary. This dimension of physical togetherness or separation is of particular importance to domains such as learning and working, where the physical social component may be critical. There may be instances where people are already physically together, such as students who are attending school physically who are trying to use social VR as part of their curriculum, or team members in a workplace who are trying to use social VR to collaborate during a meeting. In this case, it may make sense to have participants share the same physical space and meet in the VE. This present research found that participants who were co-located moved their physical bodies more slowly, but their virtual bodies faster. While this could be due to many reasons, as aforementioned, one potential reason could be due to the social inhibition effect being stronger when in others' physical presence, compared to when in others' virtual presence. If the goal of a social interaction is to allow people to interact freely without constraints placed by the presence of others (i.e., in-person non-persons), the physical presence of others may take away from the social experience. In the same vein, in scenarios where being remote is the only viable option, such as in distance learning, technical and soft-skills training, and psychotherapy, participants may still be able to engage in equally socially enriching experience, while also taking advantage of the amount of space they have. Although, how this physical and virtual social component interacts with learning outcomes is still a domain that demands more research.

Social Norms

Given the present study suggests that virtual and physical contexts lead to differences in nonverbal behaviors, it may be possible that new social norms may arise as a result of the design of the social VR environment. Past research has shown that the design decisions of a social VR platform can give rise to new social behaviors and norms (e.g., Zheng et al., 2023). For example, how people can express their emotions and intentions through nonverbal behaviors varies across social VR platforms as a function of platform affordances. In RecRoom, people can select a non-verbal expression emoji, such as "sad", "smile," or "love," and how these options would change depending on the social context or environment (e.g., “forward”, “enemy”, or “watch out” during a quest). Likewise, in VRChat, people pat each other’s avatar’s head as a gesture of appreciation or hug (Kolesnichenko, McVeigh-Schultz, & Isbister, 2019). As social VR platforms consider the social landscape of their environments, questions such as how many users can exist in a given session or environment, if environments will be populated with agents and autonomous crowds to modify the social landscape, how environments can be designed to promote small or large group interactions, whether any context-aware data will be collected to tailor the virtual experience to the physical surroundings of the VR user, should be considered.

Tables

Table 2. Results from Linear Mixed Effects Models

Automatic Motion Head Average Speed Per Second		**Variable**	**Estimate (SE)**
	Fixed Effects	Intercept β_0	3.16e-02 (3.75e-03)*
		Slope β_1	3.23e-03 (1.81e-03)
		Virtual Context β_2	-7.73e-05 (1.81e-03)
			Estimate (SD)
	Random Effects	Group Variance Intercept u_{0g}	6.72e-05 (0.00820)
		Individual Variance Intercept u_{0ig}	1.045e-04 (0.01022)
		Residual Variance ϵ_{tig}	1.13e-04 (0.01063)
	Model Fit	*-2LL*	-925.5
		AIC	-913.5
Automatic Motion Left Hand Average Speed Per Second		**Variable**	**Estimate (SE)**
	Fixed Effects	Intercept β_0	0.0423 (0.00736)*
		Slope β_1	-0.00102 (0.00385)
		Virtual Context β_2	-0.00293 (0.00385)
			Estimate (SD)
	Random Effects	Group Variance Intercept u_{0g}	1.62e-04 (0.0127)

		Individual Variance Intercept u_{0ig}	5.46e-05 (0.00739)
		Residual Variance ϵ_{tig}	5.63e-04 (0.0237)
	Model Fit	*-2LL*	-732.3
		AIC	-720.3
Automatic Motion Right Hand Average Speed Per Second		**Variable**	**Estimate (SE)**
	Fixed Effects	Intercept β_0	0.0526 (0.00821)*
		Slope β_1	0.000384 (0.004032)
		Virtual Context β_2	-0.00256 (0.004029)
			Estimate (SD)
		Group Variance Intercept u_{0g}	0.000375 (0.0194)
		Individual Variance Intercept u_{0ig}	0.0001307 (0.0114)
		Residual Variance ϵ_{tig}	0.000589 (0.0243)
	Model Fit	*-2LL*	-696.3
		AIC	-684.3
Deliberate Motion Root Average Speed Per Second		**Variable**	**Estimate (SE)**
	Fixed Effects	Intercept β_0	0.0639 (0.0214)*
		Slope β_1	-0.000586 (0.008402)
		Virtual Context β_2	-0.02011 (0.0084002)*

			Estimate (SD)
		Group Variance Intercept u_{0g}	0.00544 (0.0738)
		Individual Variance Intercept u_{0ig}	0.00415 (0.0644)
		Residual Variance ϵ_{tig}	0.00229 (0.0478)
	Model Fit	*-2LL*	-352.1
		AIC	-340.1
Mutual Gaze		**Variable**	**Estimate (SE)**
	Fixed Effects	Intercept β_0	0.10056 (0.0293)
		Slope β_1	0.00645 (0.0136)
		Virtual Context β_2	0.00540 (0.0136)
			Estimate (SD)
		Group Variance Intercept u_{0g}	0.007402 (0.08603)
		Individual Variance Intercept u_{0ig}	0.00 (0.00)
		Residual Variance ϵ_{tig}	0.00673 (0.08205)
	Model Fit	*-2LL*	-296.9
		AIC	-284.9
Interpersonal Distance		**Variable**	**Estimate (SE)**
	Fixed Effects	Intercept β_0	2.0082 (0.190)*

		Slope β_1	0.0136 (0.0713)
		Virtual Context β_2	-0.238 (0.0713)**
			Estimate (SD)
		Group Variance Intercept u_{0g}	0.573 (0.757)
		Individual Variance Intercept u_{0ig}	0.00 (0.00)
		Residual Variance ϵ_{tig}	0.181 (0.426)
	Model Fit	*-2LL*	287.7
		AIC	299.7

Note. n = 104 for a total of 172 observations; *p < .05; Virtual Context = private (= 0) vs. public (= 1) condition; Unstandardized estimates, standard errors (SE), and standard deviations (SD); AIC = Akaike Information Criterion; –2LL = –2 Log Likelihood, relative model fit statistics.

Table 3. Study 1 descriptive statistics of the outcome variables

DV	**Condition**	**Session**	***n***	**Mean (SD)**		
Average Speed Per Second (m/s)	Private	1	32	Deliberate Motion (Root)		0.08 (0.15)
				Automatic Motion	Head	0.03 (0.01)
					Left Hand	0.04 (0.02)
					Right Hand	0.05 (0.03)
		2	51	Deliberate Motion (Root)		0.06 (0.11)
				Automatic Motion	Head	0.04 (0.02)
					Left Hand	0.04 (0.03)
					Right Hand	0.06 (0.04)
	Public	1	51	Deliberate Motion (Root)		0.03 (0.05)

				Automatic Motion	Head	0.03 (0.02)
					Left Hand	0.04 (0.03)
					Right Hand	0.05 (0.04)
		2	38	Deliberate Motion (Root)		0.04 (0.10)
				Automatic Motion	Head	0.04 (0.02)
					Left Hand	0.03 (0.02)
					Right Hand	0.05 (0.02)
Mutual Gaze (percentage)	Private	1	32	0.08 (0.07)		
		2	51	0.12 (0.13)		
	Public	1	51	0.12 (0.09)		
		2	38	0.1 (0.12)		
Interpersonal Distance (m)	Private	1	32	2.01 (1.15)		
		2	51	1.99 (0.8)		
	Public	1	51	1.79 (0.62)		
		2	38	1.84 (0.95)		

Table 4. Study 2 descriptive statistics of the outcome variables

DV	Condition	*n*	Mean (SD)		
Average Speed Per Second (m/s)	In-person	30	Deliberate Motion (Root)		0.44 (0.29)
		30	Automatic Motion	Head	0.06 (0.02)
				Left Hand	0.07 (0.03)
				Right Hand	0.12 (0.05)
	Remote	31	Deliberate Motion (Root)		0.15 (0.11)
		31	Automatic Motion	Head	0.07 (0.03)
				Left Hand	0.13 (0.07)
				Right Hand	0.16 (0.07)
Mutual Gaze (percentage)	In-person	30	0.34 (0.09)		
	Remote	31	0.39 (0.1)		

Interpersonal Distance (m)	In-person	30	2.29 (1.43)
	Remote	31	2.4 (0.6)

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