Understanding Group Behavior in Virtual Reality: A Large-Scale, Longitudinal Study in the Metaverse

Eugy Han[1]*, Mark Roman Miller[2], Nilam Ram[1,3], Kristine L. Nowak[4], Jeremy N. Bailenson[1]

[1]Department of Communication, Stanford University, USA
[2]Department of Computer Science, Stanford University, USA
[3]Department of Psychology, Stanford University, USA
[4]Department of Communication, University of Connecticut, USA
*eugyoung@stanford.edu

Han, E., Miller M.R., Ram, N., Nowak, K.L., Bailenson, J.N. (2022, May 26-30). Understanding Group Behavior in Virtual Reality: A Large-Scale, Longitudinal Study in the Metaverse. *72nd Annual International Communication Association Conference,* Paris, France.

Abstract
Networked virtual reality (VR) allows people to interact via avatars. The metaverse, or the promise of experiences in immersive digital worlds, is technologically possible but a surprisingly small number of experiments have examined group interaction in immersive collaborative virtual environments. Previous work typically involves small samples, focuses on dyads or triads, and looks at behavior in only a single session. The current study, housed within a 10-week course about VR, examined collaborative groups. Eighty-one participants, separated into eight groups, met eight times using VR headsets on a networked platform. After each meeting, participants completed a questionnaire about their experience. During half the meetings, participants wore customized avatars similar to their offline selves, while in the other half, participants wore uniform avatars. Quantitative and qualitative data demonstrated the critical role of time, both in developing group cohesion and the efficacy of VR as a medium. Embodying avatars which resembled users increased self-presence, but decreased enjoyment, compared to having uniform avatars. We discuss theoretical implications and provide suggestions for designers of VR platforms and curricula.

Key words: time, networked, virtual reality, avatars

1. Introduction

As virtual reality (VR) headsets have become more widespread, and as online content has improved in terms of quality and ease of use, more consumers are beginning to use VR. Recent estimates put the number of VR headsets sold in 2021 at over 15 million worldwide (Alsop, 2021). Not surprisingly, much of this use is driven by platforms that allow people to be networked together via avatars, for socializing, group gaming, and for work applications. Concurrently, there has been an increase in the number of these so-called social VR platforms in which these users can interact and meet. Examples of such platforms include VRChat, AltspaceVR, ENGAGE, and Facebook Horizon. While the concept of the metaverse, or the potential for fully realized and immersive digital worlds has excited users and the media, academics are still playing catchup in their research of these collaborative virtual environments (CVEs), which are computer-generated, networked simulations of environments that allow people to interact in 3D space as avatars.

Despite the rising interest in CVEs from the consumer side, as well as interest in academic work (see section 2.1), there have been few studies investigating the use of virtual reality over time. Additionally, there are competing hypotheses as to whether more usage of VR will make it “better” due to increased skill or “worse” due to the novelty effect wearing off. Of course, a full answer to that question would be nuanced and context-dependent, but at a high level there is likely a pattern among many variables of interest.

To this end, we report the results from a study involving many (n = 81) participants in medium-sized (9-14) group discussions over time (8 sessions, at least 30 minutes each) in a 10-week course on VR and its intersections with various disciplines. Our contributions are: (1) To our knowledge, the present study is the largest study that investigates the effect of time or usage of collaborative virtual environments. (2) We find multiple measures of presence (self, social, spatial) as well as other measures (entitativity, realism, and enjoyment) increase over time while in VR. (3) Customization of the participant’s avatar increases self presence and perceived realism but decreases enjoyment. (4) Factors such as prior VR use and familiarity with others before the course begins influence perceived realism, entitativity, and enjoyment. (5) The growth in these measures over time is larger than the effect of customizing the avatar. (6) During the study, we have made observations on privacy, text display, context switching, and technical problems.

2. Related Work

2.1 Collaborative Virtual Environments

While there have been a few dozen studies examining CVEs, it is difficult to assimilate them into an overall, consistent pattern of results. Table 1 presents studies which examine at least

10 groups of people who are networked in immersive VR using head-mounted displays (HMDs), or in some instances, stereoscopic projection systems. Many studies examine the fidelity of the avatars (e.g., Aseeri & Interrante, 2021) and show the different effects of varying the behavioral and photographic realism of avatars. While the general trend is that more realism causes more presence and positive experiences, there are several studies that suggest nuance here, such as Garau et al. (2003), which shows the importance of matching across visual and behavioral realism. Other studies compare interaction in CVEs to the physical world, and majority of these papers highlight the similarity between VR and behavior around physical others. Another common thread is examining asymmetries across the group. For example, Slater et al. (2000) shows that people using HMDs tend to emerge as leaders over desktop users. Finally, several studies show general efficacy of CVE systems, such as Mei et al. (2021), which shows that networked VR can link experts and novices to support ideation and decision making.

Table 1. Synchronous multi-user immersive VR studies with at least 10 or more groups

Author	Year	Groups	Size	Description
Aseeri & Interrante	2021	36	2[a]	Realistic see-through video avatars are preferred and more trusted compared to scanned or no avatar.
Bailenson et al.	2006	36	3[c]	Avatar gaze influences persuasion in women more than men.
Born et al.	2019	44	2	Physical separation during collaborative VR increases presence and performance compared to collocated users.
Chen et al.	2014	27	2[a]	Perceptual conflicts of avatar location in VR impact performance.
De Simone et al.	2019	16	2	Photorealistic video avatars produce better quality interactions than cartoonish ones.
Dey et al.	2017	13	2	Visualizing avatar physiology produces an emotional response.
Dubosc et al.	2021	18	2	Varying facial realism of avatars did not change presence or body ownership.
Dzardanova et al.	2021	46	2[a]	Compliance in a VR task is similar to compliance in the real world.
Fribourg et al.	2018	10	2	Shared VR experiences produce more efficient task performance than being alone.
Garau et al.	2003	24	2	Avatar gaze behavior has differential effects on communication quality based on avatar photorealism.

Herrera et al.	2020	51	2	Avatars with floating head and hands caused more presence and preference than full bodied avatars driven by inverse kinematics.
Hoppe et al.	2020	16	2	Redirecting location of avatars enhances communication compared to allowing overlap among avatars.
Irlitti et al.	2019	10	2	Conveying spatial awareness via avatars changes mental load and head movements.
Jiang et al.	2016	16	2	Avatars and agents similarly both influence risk behavior of other avatars in a scene.
Jiang et al.	2018	32	2	Avatars and agents similarly both influence risk behavior of other avatars in a scene.
Khojasteh & Stevenson Won	2021	10	2	Adaptation but not presence increased over time.
Li et al.	2019	26	2	Social VR produces sharing behavior that is similar to face-to-face.
McGill et al.	2016	12	2	Immersive VR introduces new ways to experience media together at-a-distance.
Mei et al.	2021	10	2[a]	VR facilitates codesign.
Moustafa & Steed	2018	10	2-4[e]	Users adapt to VR over time.
Mütterlein et al.	2018	[d]	2-4	Self-reported immersion correlates with intention to collaborate.
O'Neal et al.	2020	64	2	Parent-child conversation influences movement patterns in VR.
Pan & Steed	2017	24	2	Not having an avatar causes less trust formation compared to having an avatar and face-to-face interactions.
Pouliquen-Lardy et al.	2016	14	2	Collaboration tools can be asymmetrical across VR users.
Roth et al.	2016	18	2	Compared to face-to-face interactions, social interactions tend to be impeded with non-realistic avatars.
Roth et al.	2018	20	2	Users don't detect a mimicry algorithm on avatars.
Roth et al.	2018	25	5	Augmented social tools change presence and behavior in groups.
Rothe et al.	2020	44	2	During social video viewing in VR, users chose sending smileys and voice chat for expressing emotion.

Slater et al.	2000	10	3	Immersed users emerged as leaders of groups which included desktop users.
Smith et al.	2018	30	2	Embodied VR produced similar social presence to face-to-face interactions.
Synkownik & Mausch	2020	44	2[a]	Virtual touch produced an emotional response.
Terrier et al.	2020	60	3[b]	The presence of an audience decreases the user's performance due to social inhibition.
Toothman & Neff	2019	24	2[a]	Tracking errors impact performance and usability but not social presence.
Wang et al.	2020	26	2	Immersive VR with tracking causes more understanding than desktop VR.
Wu et al.	2021	20	2	Highly expressive avatars improve presence and task performance than low-expressive avatars.
Yeleswarapu et al.	2021	15	2	VR allows better dating assessment than traditional media.
Yoon et al.	2020	24	2	Realistic hands cause more presence than unrealistic ones.

[a] Dyads consisted of confederate and participant. [b] Triads consisted of two confederates and participant. [c] Triads consisted of one confederate and two participants. [d] Group size breakdown was not specified, but it was specified that 102 participants took part. [e] Some participants partook in multiple groups.

One important feature of past work is the size of the group. Of the 37 studies conducted, all but six of them examine dyads. While looking at dyads is important, when groups of more than two convene, head and body orientation become a unique nonverbal signal to communicate attention and other nonverbal cues (Bailenson, Beall, & Blascovich, 2002; Roth et al., 2018). Given that typical social VR platforms tend to have groups larger than dyads, to better understand the psychological processes and effects that occur there, the field needs to examine these trends. The current study is the first to systematically examine multiple sets of larger groups, each made up of around 10 individuals, simultaneously.

A second feature that is important to highlight is looking at users over time. An early longitudinal study by Bailenson and Yee (2006) examined three triads (nine participants total) who met regularly for 15 sessions over a 10-week period to collaborate for approximately 45 minutes per session. Results demonstrated that simulator sickness decreased over time. This was perhaps due to head movements also decreasing over time. Given this was a very early VR system without hand tracking or other interactive features which capture attention, users relied more on the audio channel as they became more experienced with the system. However, this early study was extremely limited by its small sample size and generalizing to larger populations requires more participants.

The other two studies to examine CVE use over time also showed this trend of behavioral adaptation to the medium. Khojasteh and Stevenson-Won (2021) followed 20 participants who were matched in random pairs over five sessions. They report qualitative analysis that showed adaptation over time, such that participants became more comfortable with the medium and learned its affordances as they collaborated in more sessions. However, the limited sample size prevents quantitative analysis of constructs such as presence and other metrics over time. Similarly, Moustafa and Steed (2018) followed 17 participants over a four-week period, and qualitatively examined 33 diary entries. They demonstrated the emergence of novel forms of social interaction. For example, participants shook their heads to indicate goodbye, given the system was head rotation only and did not support hand tracking. They demonstrated trends of increased presence but did not have the statistical power to examine quantitative data.

There are reasons to suspect that time matters in CVEs. The three studies reviewed above show adaptation behaviors and suggest (without statistical confirmation) that presence changes over time. However, these studies have small sample sizes and largely provide anecdotal evidence.

2.2 Time

People are dynamic integrated systems that evolve with place and time. In line with Dynamic Systems Theory (e.g., Newman & Newman, 2020), we seek to understand the processes by which complex human behaviors and activities emerge as different components of the system influence and change one another over time. Importantly, insights about behavioral changes that result from exposure to VR and the various stimuli presented in those environments require repeated tracking of individuals in the VR context. Studies on individuals being repeatedly exposed to media stimuli and adapting to new technologies provide unique opportunities to gain valuable insight about both the long-term and short-term processes invoked by those media (e.g., Bailenson & Yee, 2006; Brinberg et al., 2021; Harari et al., 2020; Yoshimura & Borst, 2021).

Importantly, multiple repeated measures are needed to observe when and how changes emerge. Inferences based on single session exposures or obtained through analysis of just a few sessions when participants are adjusting to the novelty of a medium are plagued with technical difficulties and can be misleading or incomplete. For example, take presence, "the subjective experience of being in one place or environment, even when one is physically situated in another" (Witmer & Singer, 1998). Lombard and Ditton (1997) postulate that first time VR users may feel unfamiliar with the advanced medium, how it is used, and the nature of the experience. This unfamiliarity, as a result, may lead to a lower sense of presence. Sagnier, Loup-Escande, and Valléry (2019) found supporting evidence for this idea: those with prior VR experience report a higher sense of presence. However, presence may continue to change as the user becomes more comfortable using the medium. A variety of perspectives (e.g., Held & Durlach, 1992; Loomis, 1992), suggest that presence will increase with experience and practice, as having "been there before" helps individuals feel as if they are in familiar places again. Alternatively, other perspectives (Lombard & Ditton, 1997) suggest that presence can decrease, as the habituation effect can cause an initially novel sense of presence to diminish. In such cases, where individuals' characteristics and repeated experiences with a medium shape how they respond, perceive, and use that media, we must obtain and analyze those repeated measures. This study leverages a unique opportunity to obtain the repeated measures data needed to study the dynamics of VR use.

2.3 Avatars

Avatars provide embodied visualizations of communication partners and have shown to lead to increased social presence, enhance trust (Gefen & Straub, 2004; Hassanein & Head, 2007), and affect behavior (Herrera & Bailenson, 2021; Waltemate et al., 2018; Yee & Bailenson, 2007). Within the context of groups, literature in computer-mediated communication has shown that in virtual communities, there are limited social cues available with which individuals can make sense of one another. One way of achieving a sense of belonging through avatars is to make the few available visual cues homogenous. The uniformity in visual appearance may act as a cue for a common social category and intensify the group identification process (see more on social identity model of deindividuation effects theory, SIDE, e.g., Kim & Park, 2011; Lea & Spears, 1991; Lee, 2004). On the other hand, too much similarity may work against group identification (see more on optimal distinctiveness theory, ODT, e.g., Brewer, 1991). More recently, it has been suggested that individual differences, such as the need for uniqueness, may act as a mediator between visual uniformity and group dynamics (Kim, 2009). However, very little is known about how differences in avatars, particularly in relation to how they are presented in a group setting (e.g., permitting freedom in customization versus having all group members share visual similarity), affect group dynamics over a long period of time.

2.4 Overview of Study

Our goal is to evaluate the roles that time and avatars play in individuals' experience and group dynamics in CVEs. In the current study, every participant had two avatars: a self-avatar (one that looked and felt like themselves) and a uniform avatar (one that was visually similar across everyone). In a virtual environment, where the available visual cues are limited, socio-demographic information of an avatar can be salient (Kim, 2009). Given this, a generic, uniform avatar that was ambiguous in both gender and ethnicity was designed for participants to create and embody.

Our research questions are: (RQ1) How will perceived self, social, and spatial presence change over time and with different avatars? (RQ2) How will perceived enjoyment of interacting in the virtual environment change over time and with different avatars? (RQ3) How will sharing visual similarity with group members influence entitativity over time? (RQ4) How will perceived realism change over time and with different avatars?

3. Methods

3.1 Participants

Participants were 101 university students participating in a 10-week course about VR. At the start of the course, all enrolled students were approached about participating in a study of how repeated exposure to VR in educational settings influenced their individual and group behavior. The current analysis includes the 81 participants who consented to participate and regularly attended the course discussion sessions (five or more of the eight weekly sessions). These 81 participants (M = 47, F = 30, Other = 2, Decline to respond = 2) were between 18 and 58 years old (*M* = 22.26, *SD* = 5.19) and identified as Asian or Asian-American (n = 30), White (n = 21), African, African-American, or Black (n = 11), Hispanic or Latinx (n = 9), multiracial (n = 5), and Middle Eastern (n = 1). Participants had varying levels of experience with VR, with 48 (59%) having never used VR prior to the course. Prior to the course, 38 participants were not familiar with anyone in their discussion group, and others reported knowing one (n_1 = 13) or more members (n_2 = 12; n_3 = 1; n_4 = 2; n_5 = 2).

3.2 Hardware and VR Equipment

Each participant was provided with an Oculus Quest 2 headset for use in their personal environment. The Oculus Quest 2 headset is a standalone head mounted display with 1832 x 1920 resolution per eye, 104.00° field of view, 90Hz refresh rate, and 6 degree-of-freedom inside-out tracking. Two of the 81 participants owned personal headsets (both PC-based Valve Index) and participated using their own devices.

3.3 Virtual Environment: ENGAGE

Weekly discussion sessions were hosted in ENGAGE, a collaborative, social VR platform designed for education. Participants met in a large, open-space area that allowed for free walking/teleporting, creating 3D drawings, suspending sticky notes in the air, writing on personal whiteboards, and adding immersive effects/3D objects. The space was large enough to accommodate use of 3D audio, which allowed groups to split into smaller groups and maintain discussion without audio overlap.

Figure 1: Participants, represented either by their customized self-avatar or a uniform avatar, (top left) interacting with immersive effects/3D objects, (top right) drawing in 3D space, (bottom left) utilizing a whiteboard, and (bottom right) having a discussion during the weekly sessions. Grey bars floating above the avatar are blocking the participants' names for the sake of privacy.

3.4 Avatar: Customized vs. Uniform

In ENGAGE, users are represented by virtual human avatars. All participants were asked to use a customized avatar (self-avatar) half the time, and a uniform avatar half the time (Figure 2). Participants were able to customize their avatars with various combinations of outfits, gender, age, skin complexion, weight, hairstyles, and facial features. The uniform avatar was designed and selected within the customization options possible within ENGAGE. Through pilot-testing and iteration, we chose an avatar that was female, given this option was visually closer to being gender-ambiguous. We chose the skin color among the options that were most ethnically ambiguous. Lastly, the uniform avatar had no hair, given hair is often used as a racial marker for faces and may trigger tendencies such as the other-race effect (MacLin & Malpass, 2001).

Figure 2: The uniform avatar, an example female customized self-avatar, and an example male customized self-avatar that participants embodied for some of their weekly discussion sessions.

3.5 Procedure

At the beginning of the course, participants selected a discussion group that fit their schedule and availability. These eight groups varied in size from 9-14 members (M = 12.63, SD = 1.77). Each week, half of the groups were assigned to one of the two avatar conditions via a randomization scheme which ensured that each group had each condition for half of the discussion session and ensured that each condition appeared equally in each of the time slots. Over the course there were eight discussion sessions. These eight sessions took place over nine weeks, as there was a one week break between the fifth and sixth session in which participants completed an individual class project in ENGAGE.

Two training sessions were held in the first two weeks of the course, during which participants were guided through how to use ENGAGE. During these training sessions, the teaching staff was available to assist when participants faced technical issues. Moreover, there was a simultaneous Zoom call open for every discussion, where users could pull off their headsets and ask for technical support (Figure 3).

The first discussion session occurred at the end of the second week, during which participants completed a series of small-group activities to further familiarize with the ENGAGE environment and its tools.

Activities during discussion session were tied to the content of that week's curriculum, but as Figure 1 shows, the activities leveraged the affordances offered by the ENGAGE platform. Example activities included working together on a shared object (Figure 1, top left), creating new computer graphic content together (Figure 1, top right), doing classic design thinking tasks with a shared whiteboard and stickies (Figure 1, bottom left) and holding small group discussions, which allowed for the nonverbal spatial constraints to be preserved, such as interpersonal distance, head orientation, and spatialized sound (Figure 1, bottom right).

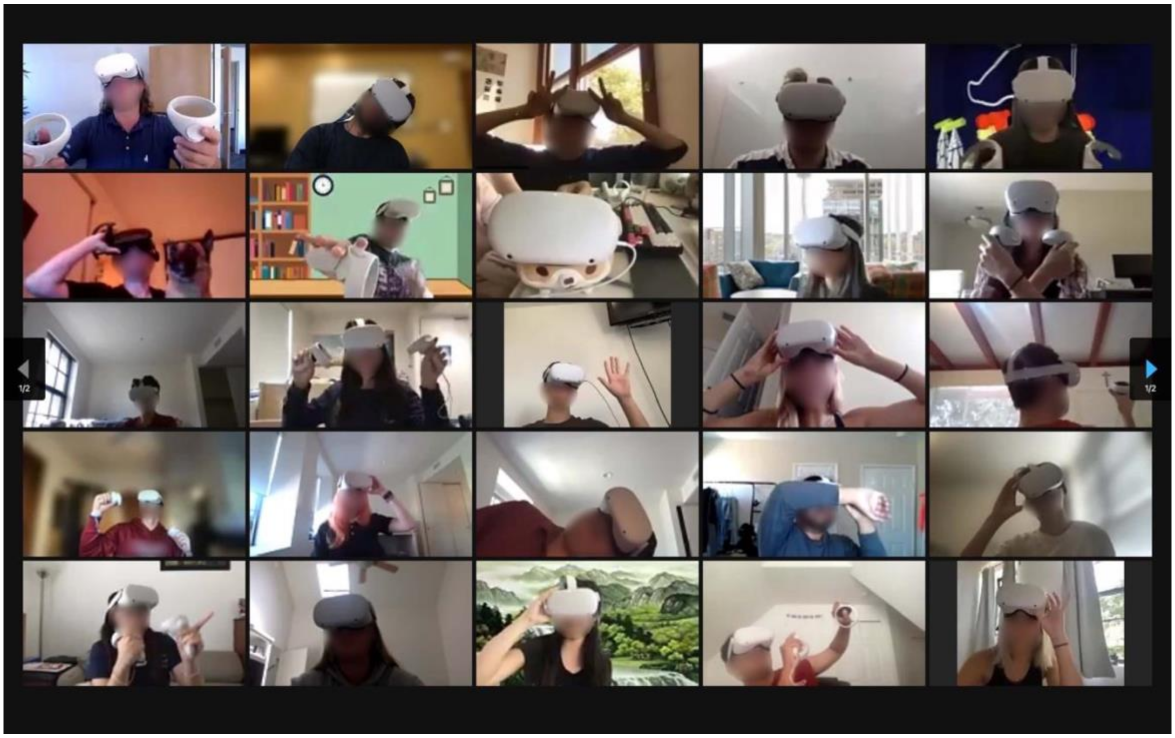

Figure 3. A Zoom window with a subset of participants in their HMDs. A Zoom technical support call was open during all in-VR activities. Faces are blocked for the sake of privacy.

3.6 Measures

Multiple aspects of individuals' attitudes and behavior were measured at the start of the study (pre-test), after each of the eight VR discussion sessions (weekly questionnaires), and at the end of the study (post-test). Scale reliability (Cronbach alpha or Spearman-Brown coefficient) was computed based on all measurement items collapsed across time. The descriptive statistics for the weekly ratings are presented in Table 2.

3.6.1 Weekly Repeated Measures

Self, Social and Spatial Presence. Individual ratings for perceived self, social, and spatial presence were obtained after each weekly VR session using items adapted from prior work (Herrera, Oh, & Bailenson, 2020; Oh, Herrera, & Bailenson, 2019). Self presence was measured as level of agreement with two statements: “I felt like my avatar’s body was my own body,” and “When something happened to my avatar, I felt like it was happening to me,” each answered using a 7-point Likert scale (1 = Strongly disagree to 7 = Strongly agree). Social presence was measured as level of agreement with two statements: “I felt like I was in the same room as my classmates,” and “I felt like my classmates were aware of my presence.” Spatial presence was measured as level of agreement with the statements, “I felt like I was really there inside the virtual environment,” and “I felt as if I could reach out and touch the objects or people in the virtual environment.” Scores for each of the three types of presence were calculated as the mean of two items, with higher scores indicating greater perceived presence. Internal consistencies, calculated using the Spearman-Brown formula (as recommended for 2-item measures by Eisinga, Grotenhuis, & Pelzer, 2013), were 0.8 for social presence, 0.86 for self presence, and 0.85 for spatial presence.

Enjoyment. Individual ratings for enjoyment in the virtual environment were obtained after each weekly VR session using two items: “How much did you like interacting in the virtual environment?” and “How much fun did you have in the virtual environment?” each answered using a 5-point Likert scale (1 = Not at all, 5 = Extremely). Weekly enjoyment scores for each individual were calculated as the mean of the two items (Spearman-Brown coefficient = 0.91), with higher scores indicating greater enjoyment in the virtual environment.

Entitativity. Entitativity, or “group-ness”, refers to the degree to which a collection of people is perceived as a single, unified entity (Campbell, 1958). Individual ratings for entitativity were obtained after each weekly VR session. Entitativity was measured by seven items adapted from Rydell and McConnell (2005) using a 7-point Likert scale (1 = Strongly disagree, 7 = Strongly agree). Sample items include “My discussion group is important to its members” and “Members of my discussion group are affected by the behaviors of other members.” Individual entitativity scores for each week were calculated as the mean of the seven items (Cronbach’s $\alpha = 0.9$), with higher scores indicating greater entitativity.

Realism. Perceived photorealism of the VR environment and people, which refers to the rendering quality of the image, was measured weekly using a single item adapted from Nowak, Hamilton, and Hammond (2009) using a slider scale (0 = Cartoon-like, 100 = Photorealistic).

Table 2. Means and Standard deviations (in parentheses) of repeated measures across 8 weeks

DV	Avatar	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Total
Self Presence	Self	3.77 (1.29)	3.58 (1.70)	4.16 (1.38)	4.00 (1.57)	4.55 (1.53)	4.42 (1.59)	4.58 (1.41)	4.34 (1.65)	4.17 (1.55)
	Uniform	3.44 (1.37)	3.78 (1.46)	3.98 (1.57)	4.15 (1.59)	4.07 (1.84)	4.07 (1.43)	4.50 (1.85)	4.28 (1.66)	4.04 (1.62)
Social Presence	Self	5.60 (0.96)	5.41 (1.24)	5.18 (0.99)	5.67 (1.04)	5.88 (0.75)	5.67 (1.04)	5.64 (0.97)	5.49 (1.13)	5.57 (1.03)
	Uniform	5.24 (1.34)	5.54 (0.94)	5.41 (1.32)	5.76 (0.86)	5.50 (0.95)	5.54 (1.02)	5.92 (1.06)	6.03 (0.67)	5.62 (1.05)
Spatial Presence	Self	5.11 (1.07)	4.04 (1.65)	4.61 (1.25)	4.63 (1.34)	4.83 (1.27)	4.95 (1.40)	5.03 (1.43)	4.80 (1.41)	4.75 (1.39)
	Uniform	4.37 (1.56)	4.88 (1.26)	4.54 (1.47)	4.88 (1.19)	4.59 (1.44)	5.01 (1.23)	5.15 (1.37)	5.42 (1.21)	4.86 (1.36)
Enjoyment	Self	3.67 (0.85)	3.08 (1.08)	3.10 (0.88)	3.11 (1.02)	3.33 (0.83)	3.45 (0.98)	3.75 (0.97)	3.42 (1.03)	3.36 (0.98)
	Uniform	3.56 (1.01)	3.53 (0.75)	3.27 (1.01)	3.38 (0.89)	3.31 (0.90)	3.24 (1.06)	3.97 (0.92)	3.69 (0.96)	3.50 (0.96)
Entitativity	Self	5.18 (1.10)	5.07 (0.94)	5.18 (0.96)	5.05 (0.98)	5.63 (0.72)	5.33 (0.99)	5.33 (0.89)	5.28 (0.86)	5.25 (0.94)
	Uniform	4.82 (0.92)	5.13 (0.90)	5.17 (0.93)	5.44 (0.87)	5.12 (0.98)	5.07 (0.99)	5.62 (0.85)	5.63 (0.76)	5.25 (0.93)
Realism	Self	37.00 (20.02)	35.81 (21.01)	32.90 (17.96)	37.40 (22.88)	45.82 (23.12)	43.68 (21.24)	42.31 (23.99)	41.76 (22.73)	39.65 (21.82)
	Uniform	29.62 (19.54)	34.28 (20.86)	36.82 (18.91)	38.21 (20.32)	36.31 (21.87)	39.15 (21.51)	45.70 (24.12)	40.78 (19.13)	37.66 (21.16)

3.6.2 Individual Differences Measures

Prior VR Use. Individual prior experience with VR was measured at the start of the study. Individuals were asked if they had ever used a VR headset before (1 = Yes, 0 = No), and if they had, how many times they had experienced VR (1 = Once, 2 = Twice, 3 = Three times, 4 = More than three times) (n_0 = 41, n_1 = 6, n_2 = 6, n_3 = 7, n_{3+} = 20, declined to or did not respond = 1).

Prior Relationships. The number of discussion group members individuals were familiar with prior to the academic quarter was measured at the start of the study (e.g., 0, 1, 2, 3 people), to evaluate if there was an influence of having prior familiarity with any group members on how the dependent variables evolve over time (*M* = 0.98, *SD* = 1.24).

Group Identification. Individual ratings for group identification, one's identification to a group they belong to, such as an organization, club, or sports team, were measured at the start of the study. Group identification was measured using eight items adapted from Leach et al. (2008)'s in-group identification scale and Mael and Ashforth (1992)'s organizational identification scale. Sample items, each answered using a 7-point Likert scale (1 = Strongly disagree, 7 = Strongly agree), included: "The fact that I am part of my group is an important part of my identity" and "When I talk about my group, I usually say 'we' rather than 'they.'" Individual group identification scores were calculated as the mean of the eight items (Cronbach's α = 0.89), with higher scores indicating greater identification with the group (*M* = 5.35, *SD* = 0.97).

3.7 Data Analysis

Individual differences in how individuals' feelings and behavior changed over time and in relation to type of avatar (self vs. uniform), and how these effects were related to individual differences in group identification, prior relationships, and prior VR experience were examined using linear growth models with time-invariant and time-varying covariates (Grimm, Ram, & Estabrook, 2016). Specifically, each of the six repeated measures outcomes were modeled as

$$outcome_{ti} = \beta_{0i} + \beta_{1i}(week_{ti}) + \beta_{2i}(avatar_{ti}) + e_{ti}$$

where the outcome of interest for person *i* at occasion *t*, $outcome_{ti}$ is modeled as a function of a person-specific intercept, β_{0i}, a person-specific linear slope, β_{1i}, that indicates rate of change over time, a person-specific avatar effect, β_{2i}, that indicates the influence of avatar condition on the outcome, and residual error, e_{ti} that is assumed normally distributed with standard deviation σ_e. The person-specific intercepts, linear slopes, and avatar condition effects are in turn modeled as:

$$\beta_{0i} = \gamma_{00} + \gamma_{01}(priorRelationships_i) + \gamma_{02}(priorVR_i) + \gamma_{03}(group\ identification_i) + u_{0i}$$

$$\beta_{1i} = \gamma_{10} + \gamma_{11}(priorRelationships_i) + \gamma_{12}(priorVR_i) + u_{1i}$$

$$\beta_{2i} = \gamma_{20} + u_{2i}$$

where γ_{00} and γ_{10} describe the linear trajectory of change for the prototypical individual, γ_{20} describes the prototypical effect of the uniform avatar manipulation; γ_{01}, γ_{11}, and γ_{21} indicate how individual differences in initial level, rate of change, and avatar effect are related to prior relationships, prior VR experience, and group identification, respectively, and u_{0i}, u_{1i}, and u_{2i} are residual unexplained differences that are assumed multivariate normal distributed with standard deviations σ_{u0}, σ_{u1}, σ_{u2}, and correlations r_{u0u1}, r_{u0u2}, and r_{u1u2}. Of particular interest are the significance and direction of the γ_{10} parameter indicating prototypical rate of change, and γ_{20} parameter indicating the prototypical avatar effect. How these individual differences in change across the repeated measures are related to (moderated by) other individual differences focus on interpretation of the γ_{01-03} and γ_{11-12} parameters.

All models were fit to the data in R using the lme4 (Bates et al., 2015) and lmerTest (Kuznetsova, Brockhoff, & Christensen, 2017) libraries with restricted maximum likelihood estimation and visualized using the ggplot2 library (Valero-Mora, 2010). Incomplete data were treated as missing at random. Statistical significance was evaluated at alpha = .05. Preliminary models included the interaction between week and avatar, but this were not significant in any case and so the term was removed. Additional individual differences predictors included in the model building process, including computer self-efficacy, loneliness, Zoom fatigue (Fauville et al., 2021), video game usage, and gender were trimmed because they were not related to baseline levels, rates of change, or avatar effects for any of the six outcomes. In cases where the data did not support all random effects, the u_{2i} term was removed. After the main models were run, a variety of follow-up models were used to check sensitivity and robustness of results. These included an examination of the random effects structure through expansion of the residual error terms so that they could be time-specific (i.e., removing the homogeneity of error assumption) and sensitivity to potential outlier observations. In all cases the pattern of results remained intact. Thus, results from the more parsimonious models are reported.

4. Results

Results from growth models with time-varying predictors (week and avatar) and time-invariant predictors (prior relationships, prior VR experience, and group identification) are presented separately for all six outcomes (self presence, social presence, spatial presence, enjoyment, entitativity, realism) models examining each of the six models are chronicled below. Plots of the raw data, overlayed with relevant prototypical trajectories are given in Figure 4. Model parameters are reported in raw form (along with *p*-values) to facilitate interpretation of effects in the actual units of the predictors (e.g., number of weeks of exposure, and avatar condition; self = 0 versus uniform = 1) and inferences to practical interventions.

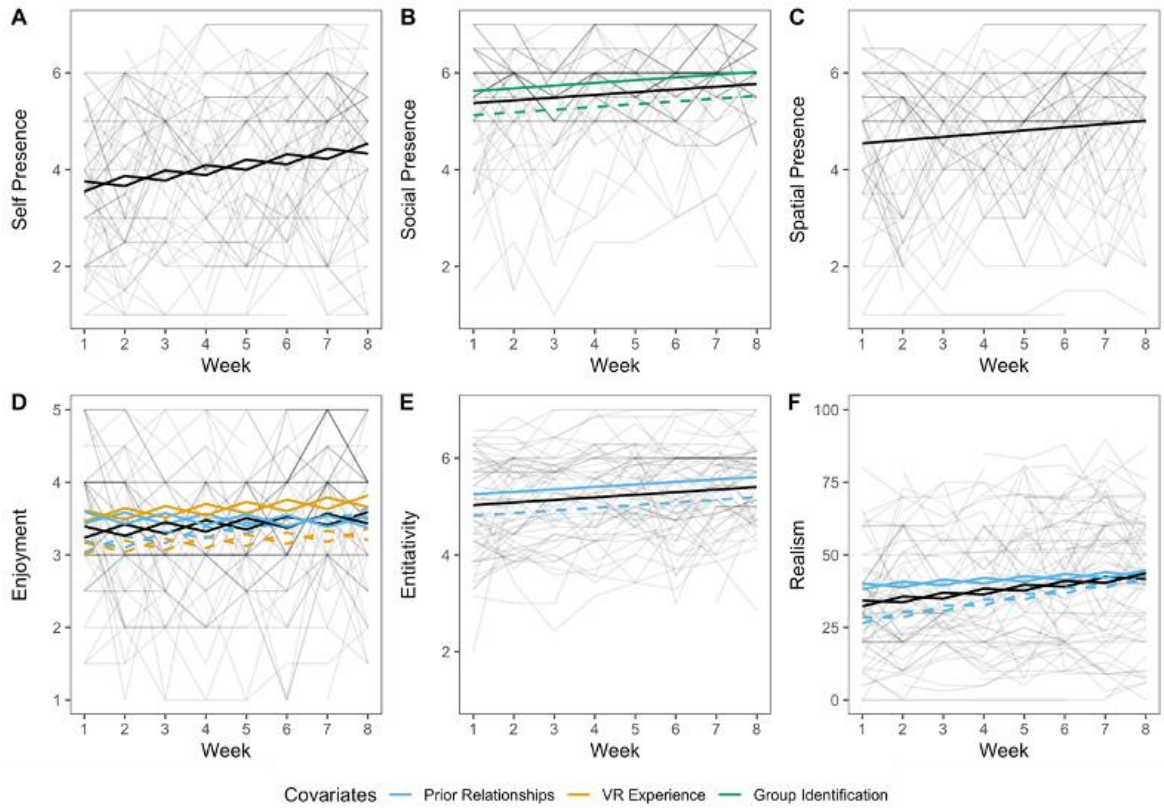

Figure 4. Dependent variables over time. Panels A-F show change over time and in relation to the avatar manipulation for each of the six outcome variables. Individual trajectories (raw data) are indicated by the light gray lines. Model-implied prototypical trajectories are indicated by the thick black lines and are shown for two hypothetical cases where the avatar conditions alternated weekly (and thus produce oscillations). When individual differences were related to baseline or rate of change, additional model implied trajectories for individuals 1 SD above (solid color) and 1 SD below (dashed color) the average score are indicated by thick colored lines.

4.1 Self Presence

The prototypical participant's self presence increased from an initial value of $\gamma_{00} = 3.75$, $p < 0.001$ (on a 7-point scale) at a rate of $\gamma_{01} = 0.101$, $p = 0.0035$, points per week over the eight weeks of study. There was a significant effect of the avatar manipulation, such that in the VR sessions where individuals used a uniform avatar individuals had lower self presence, $\gamma_{20} = -0.21$, $p = 0.0205$ (RQ1). Prototypical trajectories for how self presence changed over time for individuals who alternated weekly between the two avatar conditions are shown as bold black lines in Panel A of Figure 4.

There was no evidence that individual differences in group identification, prior relationships, or prior VR experience were uniquely related to baseline levels of self presence (*p*s > 0.35). There was also no evidence that individual differences in prior relationships or prior VR experience were uniquely related to rate of increase in self presence (*p*s > 0.63).

4.2 Social Presence

The prototypical participant's social presence increased from an initial value of $\gamma_{00} = 5.23$, $p < 0.001$ (on a 7-point scale) at a rate of $\gamma_{10} = 0.068$, $p = 0.014$, points per week over the eight weeks of study. There was no evidence that the avatar manipulation influenced social presence, $\gamma_{20} = 0.055$, $p = 0.40$ (RQ1). A prototypical trajectory showing how social presence changed over time is in Panel B of Figure 4.

Individuals with higher group identification had higher baseline levels of social presence, $\gamma_{01} = 0.25$, $p = 0.0205$. The implied differences are evident in the contrast between the green solid (+1SD on group identification) and dashed (-1SD on group identification) in Panel B of Figure 4. There was no evidence that individual differences in prior relationships, or prior VR experience were uniquely related to baseline levels of social presence (*p*s > 0.3). There was also no evidence that individual differences in prior relationships or prior VR experience were uniquely related to rate of increase in social presence (*p*s > 0.49).

4.3 Spatial Presence

The prototypical participant's spatial presence increased from an initial value of $\gamma_{00} = 4.33$, $p = 0.001$ (on a 7-point scale) at a rate of $\gamma_{10} = 0.083$, $p = 0.014$, points per week over the eight weeks of study. There was no evidence that the avatar manipulation influenced spatial presence, $\gamma_{20} = 0.069$, $p = 0.38$ (RQ1). Prototypical trajectories showing how spatial presence changed over time are shown as bold black lines in Panel C of Figure 4.

There was no evidence that individual differences in group identification, prior relationships, or prior VR experience were uniquely related to baseline levels of spatial presence (*p*s > 0.106). There was no evidence that individual differences in prior relationships or prior VR experience were uniquely related to rate of increase in spatial presence (*p*s > 0.43).

4.4 Enjoyment

The prototypical participant's enjoyment increased from an initial value of $\gamma_{00} = 3.057$, $p < 0.001$ (on a 5-point scale) at a rate of $\gamma_{10} = 0.061$, $p = 0.0018$, points per week over the eight weeks of study. Enjoyment was slightly higher during weeks when individuals used the uniform avatar, $\gamma_{20} = 0.16$, $p = 0.0106$ (RQ2). Prototypical trajectories showing how enjoyment changed over time for individuals who alternated weekly between the two avatar conditions are shown as bold black lines in Panel D of Figure 4.

Individuals with more prior relationships had higher baseline levels of enjoyment, $\gamma_{01} = 0.22$, $p = 0.023$. The implied differences are evident in the contrast between the blue solid (+1SD on prior relationships) and dashed (-1SD on prior relationships) in Panel D of Figure 4. Individuals with more prior VR experience had higher baseline levels of enjoyment, $\gamma_{02} = 0.24$, $p = 0.035$. The implied differences are evident in the contrast between the orange solid (+1SD on prior VR) and dashed (-1SD on prior VR) in Panel D of Figure 4. There was no evidence that individual differences in group identification were uniquely related to baseline levels of enjoyment ($p = 0.37$). Although there was no evidence that individual differences in prior relationships were uniquely related to rate of increase in enjoyment ($p = 0.96$), the enjoyment of individuals with more prior VR experience did not increase as much as those with no prior VR experience, $\gamma_{12} = -0.044$, $p = 0.0079$, as seen in differential rates of increase of the yellow solid and dashed lines.

4.5 Entitativity

The prototypical participant's entitativity increased from an initial value of $\gamma_{00} = 5.0096$, $p < 0.001$ (on a 7-point scale) at a rate of $\gamma_{10} = 0.059$, $p = 0.0016$, points per week over the eight weeks of study. There was no evidence that the avatar manipulation influenced entitativity, $\gamma_{20} = -0.022$, $p = 0.62$ (RQ3). Prototypical trajectories showing how entitativity changed over time for individuals who alternated weekly between the two avatar conditions are shown as bold black lines in Panel E of Figure 4.

Individuals with more prior relationships had higher baseline levels of entitativity, $\gamma_{01} = 0.22$, $p = 0.04$. The implied differences are evident in the contrast between the yellow solid (+1SD on group identification) and dashed (-1SD on group identification) in Panel E of Figure 4. There was no evidence that individual differences in group identification or prior VR experience were uniquely related to baseline levels of entitativity (ps > 0.068). There was also no evidence that individual differences in prior relationships or prior VR experience were uniquely related to rate of increase in entitativity (ps > 0.59).

4.6 Realism

The prototypical participant's perception of realism increased from an initial value of $\gamma_{00} = 35.62$, $p = < 0.001$ (on the 0 to 100, cartoon-like to photorealistic scale) at a rate of $\gamma_{10} = 0.88$, $p = 0.057$, points per week over the 8 weeks of study. There was a significant effect of the avatar manipulation, such that the VR sessions where individuals used a uniform avatar were viewed as less realistic (i.e., more "cartoon-like"), $\gamma_{20} = -2.028$, $p = 0.035$ (RQ4). Prototypical trajectories showing how realism changed over time for individuals who alternated weekly between the two avatar conditions are shown as bold black lines in Panel F of Figure 4.

Individuals with more prior relationships had higher baseline levels of realism, γ_{01} = 5.89, p = 0.0106. The implied differences are evident in the contrast between the yellow solid (+1SD on group identification) and dashed (-1SD on group identification) in Panel F of Figure 4. There was no evidence that individual differences in group identification or prior VR experience were uniquely related to baseline levels of realism (ps > 0.41). The realism of individuals with more prior relationships increased less than individual with fewer prior relationships, γ_{11} = -0.704, p = 0.0405. The implied differences are evident in the contrast between the slopes of the light blue solid (+1SD on prior relationships) and dashed (-1SD on prior relationships) in Panel F of Figure 4. However, there was no evidence that individual differences in prior VR experience was uniquely related to rate of increase in realism (p = 0.108).

5. Discussion

5.1 Summary of Results

Overall, the results showed that all measures, including self, social, and spatial presence, enjoyment, entitativity, and realism increased over time. This underscores the critical role that time plays in how people's experience in VR evolves. Given this, it is possible that once participants adapt to the medium and are no longer uncomfortable with the novelty of the technology, they are able to reap the advantages that VR and CVEs provide and feel more presence and connectedness.

We also found that, during the weeks where participants were in the uniform avatars (i.e., visually like one another), their self presence was lower and they perceived the VR environment and others as more cartoon-like (less photorealistic), but they had greater enjoyment interacting in the virtual environment. Furthermore, while entitativity did increase over time, visual uniformity did not have an effect on entitativity. Similarly, while those who had prior relationships with group members did start with a higher level of entitativity, there was no evidence that this individual difference was uniquely related to the increase in entitativity. This is neither supported by the SIDE nor ODT theory, raising the possibility that time played a unique role in the relationship between visual similarity/uniformity and group dynamics. Although the number of limited cues in a virtual environment may make differences among group members more salient and interfere with the group identification process, this does not hold true over time. In fact, given the effect of visual uniformity on self presence, and given the importance that self presence has on immersion, and, in turn, attention and connection to the environment, it may be unfavorable to have a uniform avatar in a group setting and suppress individuals' visual cues.

5.2 Limitations and Future Directions

In this study there were several limitations. First, while there was a diverse set of participants in terms of gender and ethnicity, it was still a convenience sample with college undergraduates, and a better sample would have more variance in age and other demographic characteristics. Second, we focused on self-report questionnaires. Future research should examine the tracking data, utterances, and other behavioral data from the group interactions. While we did record that data from the current study, it is beyond the scope of this paper to present it. Finally, we were limited by the processing abilities of "standalone VR" as implemented by the Oculus Quest 2. This had impacts on the realism of avatars, scenes, and other aspects of the VR experience. Future work will examine VR that is more processing-intensive to test more detailed scenes and avatars.

6. Conclusion

In this study, we investigated the effect of time on multiple measures in a collaborative virtual environment. The three forms of presence as well as realism, entitativity, and enjoyment all increased over time. We additionally investigated the role of visual appearance of avatars amongst members of a group, and found that, in accordance with previous literature, avatar appearance plays a significant role in some, but not all, aspects of individuals' perception and experience in VR. As social VR and CVEs become more popular and perhaps integrated into everyday life, it is important to study not only at one moment in time but also across time, as well as how they transform the effects of factors such as avatar appearance and individual differences on VR use.

References

Alsop, T. (2018). *Topic: Virtual Reality (VR)*. www.statista.com; Statista. https://www.statista.com/topics/2532/virtual-reality-vr/

Aseeri, S., & Interrante, V. (2021). The Influence of Avatar Representation on Interpersonal Communication in Virtual Social Environments. *IEEE Transactions on Visualization and Computer Graphics*, *27*(5), 2608-2617. https://doi.org/10.1109/TVCG.2021.3067783

Bailenson, J. N., Beall, A. C., & Blascovich, J. (2002). Gaze and task performance in shared virtual environments. *The journal of visualization and computer animation*, *13*(5), 313-320. https://doi.org/10.1002/vis.297

Bailenson, J. N., Beall, A. C., Loomis, J., Blascovich, J., & Turk, M. (2005). Transformed social interaction, augmented gaze, and social influence in immersive virtual environments. *Human communication research*, *31*(4), 511-537. https://doi.org/10.1111/j.1468-2958.2005.tb00881.x

Bailenson, J. N., & Yee, N. (2006). A longitudinal study of task performance, head movements, subjective report, simulator sickness, and transformed social interaction in collaborative virtual environments. *Presence: Teleoperators and Virtual Environments*, *15*(6), 699-716. https://doi.org/10.1162/pres.15.6.699

Bates, D., Mächler, M., Bolker, B., & Walker, S. (2015). Fitting Linear Mixed-Effects Models Using lme4. *Journal of Statistical Software*, 67(1), 1–48. https://doi.org/10.18637/jss.v067.i01

Born, F., Sykownik, P., & Masuch, M. (2019, August). Co-located vs. remote gameplay: The role of physical co-presence in multiplayer room-scale vr. In *2019 IEEE Conference on Games (CoG)* (pp. 1-8). IEEE. https://doi.org/10.1109/CIG.2019.8848001

Brewer, M. B. (1991). The social self: On being the same and different at the same time. *Personality and social psychology bulletin*, *17*(5), 475-482. https://doi.org/10.1177/0146167291175001

Brinberg, M., Vanderbilt, R. R., Solomon, D. H., Brinberg, D., & Ram, N. (2021). Using technology to unobtrusively observe relationship development. *Journal of Social and Personal Relationships*, 02654075211028654. https://doi.org/10.1177/02654075211028654

Campbell, D. T. (1958). Common fate, similarity, and other indices of the status of aggregates of persons as social entities. *Behavioral science*, *3*(1), 14.

Chen, W., Clavel, C., Férey, N., & Bourdot, P. (2014). Perceptual conflicts in a multi-stereoscopic immersive virtual environment: Case study on face-to-face interaction through an avatar. *Presence: Teleoperators and Virtual Environments*, *23*(4), 410-429. https://doi.org/10.1162/PRES_a_00209

De Simone, F., Li, J., Debarba, H. G., El Ali, A., Gunkel, S. N., & Cesar, P. (2019, March). Watching videos together in social virtual reality: An experimental study on user's QoE. In *2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)* (pp. 890-891). IEEE. https://doi.org/10.1109/VR.2019.8798264

Dey, A., Piumsomboon, T., Lee, Y., & Billinghurst, M. (2017, May). Effects of sharing physiological states of players in a collaborative virtual reality gameplay. In *Proceedings of the 2017 CHI conference on human factors in computing systems* (pp. 4045-4056). https://doi.org/10.1145/3025453.3026028

Dubosc, C., Gorisse, G., Christmann, O., Fleury, S., Poinsot, K., & Richir, S. (2021). Impact of avatar facial anthropomorphism on body ownership, attractiveness and social presence in collaborative tasks in immersive virtual environments. *Computers & Graphics*. https://doi.org/10.1016/j.cag.2021.08.011

Dzardanova, E., Kasapakis, V., Gavalas, D., & Sylaiou, S. (2021). Virtual reality as a communication medium: a comparative study of forced compliance in virtual reality versus physical world. *Virtual Reality*, 1-21. https://doi.org/10.1007/s10055-021-00564-9

Eisinga, R., Te Grotenhuis, M., & Pelzer, B. (2013). The reliability of a two-item scale: Pearson, Cronbach, or Spearman-Brown?. *International journal of public health*, *58*(4), 637-642. https://doi.org/10.1007/s00038-012-0416-3

Fauville, G., Luo, M., Queiroz, A. C. M., Bailenson, J. N., & Hancock, J. (2021). Zoom Exhaustion & Fatigue Scale. *Computers in Human Behavior Reports*, 4. https://doi.org/10.1016/j.chbr.2021.100119

Fribourg, R., Argelaguet, F., Hoyet, L., & Lécuyer, A. (2018, March). Studying the sense of embodiment in VR shared experiences. In *2018 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)* (pp. 273-280). IEEE. https://doi.org/10.1109/VR.2018.8448293

Garau, M., Slater, M., Vinayagamoorthy, V., Brogni, A., Steed, A., & Sasse, M. A. (2003, April). The impact of avatar realism and eye gaze control on perceived quality of communication in a shared immersive virtual environment. In *Proceedings of the SIGCHI conference on Human factors in computing systems* (pp. 529-536). https://doi.org/10.1145/642611.642703

Gefen, D., & Straub, D. W. (2004). Consumer trust in B2C e-Commerce and the importance of social presence: experiments in e-Products and e-Services. *Omega*, *32*(6), 407-424. https://doi.org/10.1016/j.omega.2004.01.006

Grimm, K. J., Ram, N., & Estabrook, R. (2016). *Growth modeling: Structural equation and multilevel modeling approaches*. Guilford Publications.

Harari, G. M., Müller, S. R., Stachl, C., Wang, R., Wang, W., Bühner, M., ... & Gosling, S. D. (2020). Sensing sociability: Individual differences in young adults' conversation, calling, texting, and app use behaviors in daily life. *Journal of personality and social psychology, 119*(1), 204. https://doi.org/10.1037/pspp0000245

Hassanein, K., & Head, M. (2007). Manipulating perceived social presence through the web interface and its impact on attitude towards online shopping. *International journal of human-computer studies*, *65*(8), 689-708. https://doi.org/10.1016/j.ijhcs.2006.11.018

Held, R. M., & Durlach, N. I. (1992). Telepresence. *Presence: Teleoperators & Virtual Environments*, *1*(1), 109-112. https://doi.org/10.1162/pres.1992.1.1.109

Herrera, F., & Bailenson, J. N. (2021). Virtual reality perspective-taking at scale: Effect of avatar representation, choice, and head movement on prosocial behaviors. *new media & society*, *23*(8), 2189-2209. https://doi.org/10.1177/1461444821993121

Herrera, F., Oh, S. Y., & Bailenson, J. N. (2020). Effect of behavioral realism on social interactions inside collaborative virtual environments. *Presence*, *27*(2), 163-182. https://doi.org/10.1162/pres_a_00324

Hoppe, A. H., van de Camp, F., & Stiefelhagen, R. (2021). ShiSha: Enabling Shared Perspective With Face-to-Face Collaboration Using Redirected Avatars in Virtual Reality. *Proceedings of the ACM on Human-Computer Interaction*, *4*(CSCW3), 1-22. https://doi.org/10.1145/3432950

Irlitti, A., Piumsomboon, T., Jackson, D., & Thomas, B. H. (2019). Conveying spatial awareness cues in xR collaborations. *IEEE transactions on visualization and computer graphics*, *25*(11), 3178-3189. https://doi.org/10.1109/TVCG.2019.2932173

Jiang, Y., O'Neal, E., Rahimian, P., Yon, J. P., Plumert, J. M., & Kearney, J. K. (2016, July). Action coordination with agents: Crossing roads with a computer-generated character in a virtual environment. In *Proceedings of the ACM Symposium on Applied Perception* (pp. 57-64). https://doi.org/10.1145/2931002.2931003

Jiang, Y., O'Neal, E. E., Rahimian, P., Yon, J. P., Plumert, J. M., & Kearney, J. K. (2018). Joint action in a virtual environment: Crossing roads with risky vs. safe human and agent partners. *IEEE transactions on visualization and computer graphics*, *25*(10), 2886-2895. https://doi.org/10.1109/TVCG.2018.2865945

Khojasteh, N., & Won, A. S. (2021). Working Together on Diverse Tasks: A Longitudinal Study on Individual Workload, Presence and Emotional Recognition in Collaborative Virtual Environments. *Frontiers in Virtual Reality*, *2*, 53. https://doi.org/10.3389/frvir.2021.643331

Kim, J. (2009). "I want to be different from others in cyberspace" The role of visual similarity in virtual group identity. *Computers in Human Behavior*, *25*(1), 88-95. https://doi.org/10.1016/j.chb.2008.06.008

Kim, J., & Park, H. S. (2011). The effect of uniform virtual appearance on conformity intention: Social identity model of deindividuation effects and optimal distinctiveness theory. *Computers in Human Behavior*, *27*(3), 1223-1230. https://doi.org/10.1016/j.chb.2011.01.002

Kuznetsova, A., Brockhoff, P. B., & Christensen, R. H. B. (2017). lmerTest Package:

Tests in Linear Mixed Effects Models. *Journal of Statistical Software*, *82*(13), 1–26. https://doi.org/10.18637/jss.v082.i13

Lea, M., & Spears, R. (1991). Computer-mediated communication, de-individuation and group decision-making. *International journal of man-machine studies*, *34*(2), 283-301. https://doi.org/10.1016/0020-7373(91)90045-9

Leach, C. W., Van Zomeren, M., Zebel, S., Vliek, M. L., Pennekamp, S. F., Doosje, B., ... & Spears, R. (2008). Group-level self-definition and self-investment: a hierarchical (multicomponent) model of in-group identification. *Journal of personality and social psychology*, *95*(1), 144. https://doi.org/10.1037/0022-3514.95.1.144

Lee, E. J. (2004). Effects of visual representation on social influence in computer-mediated communication: Experimental tests of the social identity model of deindividuation effects. *Human Communication Research*, *30*(2), 234-259. https://doi.org/10.1111/j.1468-2958.2004.tb00732.x

Li, J., Kong, Y., Röggla, T., De Simone, F., Ananthanarayan, S., De Ridder, H., ... & Cesar, P. (2019, May). Measuring and understanding photo sharing experiences in social Virtual Reality. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems* (pp. 1-14). https://doi.org/10.1145/3290605.3300897

Lombard, M., & Ditton, T. (1997). At the heart of it all: The concept of presence. *Journal of computer-mediated communication*, *3*(2), JCMC321. https://doi.org/10.1111/j.1083-6101.1997.tb00072.x

Loomis, J. M. (1992). Distal attribution and presence. *Presence: Teleoperators & Virtual Environments*, *1*(1), 113-119. https://doi.org/10.1162/pres.1992.1.1.113

MacLin, O. H., & Malpass, R. S. (2001). Racial categorization of faces: The ambiguous race face effect. *Psychology, Public Policy, and Law*, *7*(1), 98. https://doi.org/10.1037/1076-8971.7.1.98

Mael, F., & Ashforth, B. E. (1992). Alumni and their alma mater: A partial test of the reformulated model of organizational identification. *Journal of organizational Behavior*, *13*(2), 103-123. https://doi.org/10.1002/job.4030130202

McGill, M., Williamson, J. H., & Brewster, S. (2016). Examining the role of smart TVs and VR HMDs in synchronous at-a-distance media consumption. *ACM Transactions on Computer-Human Interaction (TOCHI)*, *23*(5), 1-57. https://doi.org/10.1145/2983530

Mei, Y., Li, J., de Ridder, H., & Cesar, P. (2021, May). CakeVR: A Social Virtual Reality (VR) Tool for Co-designing Cakes. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems* (pp. 1-14). https://doi.org/10.1145/3411764.3445503

Moustafa, F., & Steed, A. (2018, November). A longitudinal study of small group interaction in social virtual reality. In *Proceedings of the 24th ACM Symposium on Virtual Reality Software and Technology* (pp. 1-10).

https://doi.org/10.1145/3281505.3281527

Mütterlein, J., Jelsch, S., & Hess, T. (2018). Specifics of Collaboration in Virtual Reality: How Immersion Drives the Intention to Collaborate. In *PACIS* (p. 318).

Newman, B. M., & Newman, P. R. (2020). *Chapter 4 - Dynamic systems theory*. In *Theories of Adolescent Development* (pp. 77–112). Academic Press. https://doi.org/10.1016/B978-0-12-815450-2.00004-8

Nowak, K. L., Hamilton, M. A., & Hammond, C. C. (2009). The effect of image features on judgments of homophily, credibility, and intention to use as avatars in future interactions. *Media Psychology*, *12*(1), 50-76. https://doi.org/10.1080/15213260802669433

Oh, C., Herrera, F., & Bailenson, J. (2019). The effects of immersion and real-world distractions on virtual social interactions. *Cyberpsychology, Behavior, and Social Networking*, *22*(6), 365-372. https://doi.org/10.1089/cyber.2018.0404

O'Neal, E. E., Zhou, S., Jiang, Y., Kearney, J. K., & Plumert, J. M. (2021). Let's Cross the Next One: Parental Scaffolding of Prospective Control Over Movement. *Child Development*, *92*(2), e173-e185. https://doi.org/10.1111/cdev.13457

Pan, Y., & Steed, A. (2017). The impact of self-avatars on trust and collaboration in shared virtual environments. *PloS one*, *12*(12), e0189078. https://doi.org/10.1371/journal.pone.0189078

Pouliquen-Lardy, L., Milleville-Pennel, I., Guillaume, F., & Mars, F. (2016). Remote collaboration in virtual reality: asymmetrical effects of task distribution on spatial processing and mental workload. *Virtual Reality*, *20*(4), 213-220. https://doi.org/10.1007/s10055-016-0294-8

Roth, D., Klelnbeck, C., Feigl, T., Mutschler, C., & Latoschik, M. E. (2018, March). Beyond replication: Augmenting social behaviors in multi-user virtual realities. In *2018 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)* (pp. 215-222). IEEE. https://doi.org/10.1109/VR.2018.8447550

Roth, D., Lugrin, J. L., Galakhov, D., Hofmann, A., Bente, G., Latoschik, M. E., & Fuhrmann, A. (2016, March). Avatar realism and social interaction quality in virtual reality. In *2016 IEEE Virtual Reality (VR)* (pp. 277-278). IEEE. https://doi.org/10.1109/VR.2016.7504761

Rothe, S., Schmidt, A., Montagud, M., Buschek, D., & Hußmann, H. (2021). Social viewing in cinematic virtual reality: a design space for social movie applications. *Virtual Reality*, *25*(3), 613-630. https://doi.org/10.1007/s10055-020-00472-4

Rydell, R. J., & McConnell, A. R. (2005). Perceptions of entitativity and attitude change. *Personality and Social Psychology Bulletin*, *31*(1), 99-110. https://doi.org/10.1177/0146167204271316

Sagnier, C., Loup-Escande, E., & Valléry, G. (2019, July). Effects of gender and prior experience in immersive user experience with virtual reality. In *International Conference on Applied Human Factors and Ergonomics* (pp. 305-314). Springer, Cham. https://doi.org/10.1007/978-3-030-19135-1_30

Slater, M., Sadagic, A., Usoh, M., & Schroeder, R. (2000). Small-group behavior in a virtual and real environment: A comparative study. *Presence*, *9*(1), 37-51. https://doi.org/10.1162/105474600566600

Smith, H. J., & Neff, M. (2018, April). Communication behavior in embodied virtual reality. In *Proceedings of the 2018 CHI conference on human factors in computing systems* (pp. 1-12). https://doi.org/10.1145/3173574.3173863

Sykownik, P., & Masuch, M. (2020, November). The experience of social touch in multi-user virtual reality. In *26th ACM symposium on virtual reality software and technology* (pp. 1-11). https://doi.org/10.1145/3385956.3418944

Terrier, R., Martin, N., Lacoche, J., Gouranton, V., & Arnaldi, B. (2020). Do Distant or Colocated Audiences Affect User Activity in VR?. In *Transactions on Computational Science XXXVII* (pp. 1-18). Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-662-61983-4_1

Toothman, N., & Neff, M. (2019, March). The impact of avatar tracking errors on user experience in VR. In *2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)* (pp. 756-766). IEEE. https://doi.org/10.1109/VR.2019.8798108

Valero-Mora, P. M. (2010). ggplot2: Elegant Graphics for Data Analysis. *Journal of Statistical Software*, Book Reviews, 35(1), 1–3. https://doi.org/10.18637/jss.v035.b01

Waltemate, T., Gall, D., Roth, D., Botsch, M., & Latoschik, M. E. (2018). The impact of avatar personalization and immersion on virtual body ownership, presence, and emotional response. *IEEE transactions on visualization and computer graphics*, *24*(4), 1643-1652. https://doi.org/10.1109/TVCG.2018.2794629

Wang, C. Y., Sakashita, M., Ehsan, U., Li, J., & Won, A. S. (2020, April). Again, Together: Socially Reliving Virtual Reality Experiences When Separated. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems* (pp. 1-12). https://doi.org/10.1145/3313831.3376642

Witmer, B. G., & Singer, M. J. (1998). Measuring presence in virtual environments: A presence questionnaire. *Presence*, *7*(3), 225-240. https://doi.org/10.1162/105474698565686

Yee, N., & Bailenson, J. (2007). The Proteus effect: The effect of transformed self-representation on behavior. *Human communication research*, *33*(3), 271-290. https://doi.org/10.1111/j.1468-2958.2007.00299.x

Yeleswarapu, T., Nair, P., & Rangaswamy, N. (2021). “Should We Meet IRL?": Gauging Matches in Virtual Reality. In *Proceedings of 19th European Conference on Computer-Supported Cooperative Work*. European Society for Socially Embedded Technologies (EUSSET). https://doi.org/10.18420/ecscw2021_ep07

Yoon, B., Kim, H. I., Oh, S. Y., & Woo, W. (2020, November). Evaluating Remote Virtual Hands Models on Social Presence in Hand-based 3D Remote

Collaboration. In *2020 IEEE International Symposium on Mixed and Augmented Reality (ISMAR)* (pp. 520-532). IEEE. https://doi.org10.1109/ISMAR50242.2020.00080

Yoshimura, A., & Borst, C. W. (2021). A Study of Class Meetings in VR: Student Experiences of Attending Lectures and of Giving a Project Presentation. *Frontiers in Virtual Reality*, *2*, 34. https://doi.org/10.3389/frvir.2021.648619