Breaking Immersion Barriers: Smartphone Viability in Asymmetric Virtual Collaboration

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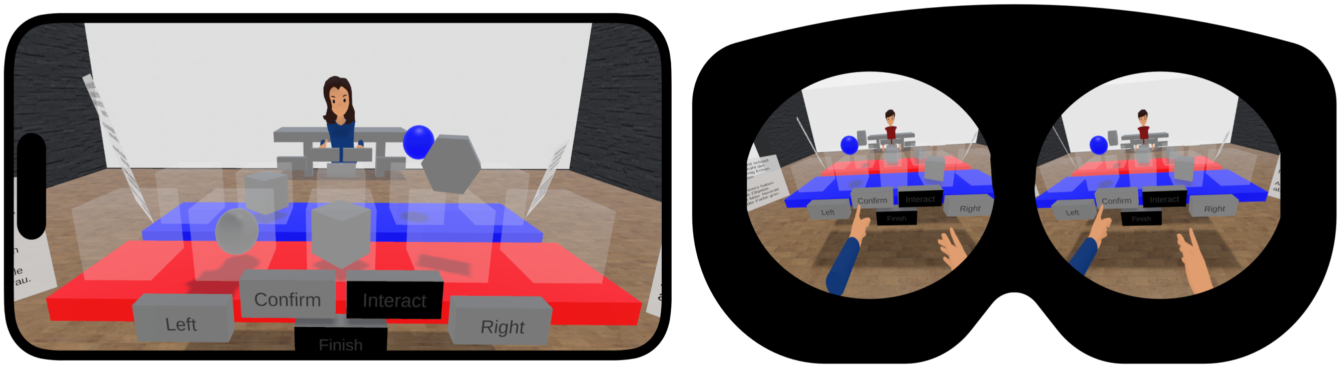

Figure 1: This figure shows the first-person perspective of the smartphone user on the left and the VR user on the right during the collaborative sorting task of our study about asymmetric interaction between a smartphone and a VR HMD based user.

Abstract

As demand grows for cross-device collaboration in virtual environments, users increasingly join shared spaces on varying hardware ranging from head-mounted displays (HMDs) to everyday lower-immersion smartphones. This paper investigates smartphone-based participation compared with fully immersive VR in dyadic asymmetric interaction. One participant joins via an HMD, while the other uses a smartphone. Through a collaborative sorting task, we evaluate self-perception (presence, embodiment), other-perception (co-presence, social presence, avatar plausibility), and task-perception (task load, enjoyment). We compare our results with previous work that examined VR-VR and desktop-VR pairings. The results show that smartphone users report lower self-perception than VR users. However, other-perception remains comparable to immersive setups. Interestingly, smartphone participants experience lower mental demand. It appears that device familiarity and intuitive interfaces can compensate for reduced immersion. Overall, our work highlights the viability of smartphones for asymmetric interaction, offering high accessibility without impairing social interaction.

CCS Concepts

• **Human-centered computing → Empirical studies in collaborative and social computing**; *Virtual reality*.

Keywords

Social VR, Smartphone, Immersion, Asymmetric Interaction, Collaboration, Virtual Reality

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1 Introduction

Current remote communication and social interaction increasingly transcend traditional boundaries. Users are no longer limited solely to messaging from smartphone to smartphone or video conferencing on desktop computers. Instead, they routinely join remote social interactions from diverse environments, be it the office, the train, or even during a walk. In response, state-of-the-art platforms like Microsoft Teams and Meta Horizon allow participation across various devices, from fully immersive Virtual Reality (VR) headsets to handheld smartphones, all within the same social virtual environment. Consequently, asymmetric interaction in which users engage with different devices in collaborative work platforms or online virtual events is becoming more prevalent [4, 35]. However, the device users are participating in can profoundly impact the user experience [3]. For instance, a VR headset user is surrounded by a virtual environment of 360 °, using tracking systems that facilitate natural social interactions similar to face-to-face communication [27]. Meanwhile, a smartphone user faces a more limited user interface and control options. The scope of smartphone control in

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the virtual environment is based on simpler input options, and the user's attention might be divided between the digital user interface and the physical surroundings that remain in their field of view.

Prior research evaluated the impact of different devices, such as desktop and VR headsets [16, 17]. Merz et al. [17] showed that desktop-based participation, compared to VR-based participation, leads to lower perceived presence, sense of embodiment, and social presence. Since the interaction mechanisms between conditions were kept constant in these studies, it can be concluded that lower immersion was a determining factor for the user experience. However, a notable gap remains in understanding how smartphones, arguably the most widely distributed and accessible communication devices but even less immersive, affect social interaction and user experience in asymmetric interaction scenarios. To fill this gap, this study investigates the following research question:

RQ: How does asymmetric interaction with smartphones affect the user experience in virtual environments?

Building on previous insights, this work evaluates an asymmetric interaction of one user with a smartphone-based setup (S) and one user with an HMD and controllers (VR). In our study, the two users collaborate on a sorting task based on previous work [16]. We then compare our collected data with one asymmetric pairing (Desktop - VR) and one symmetric pairing (VR - VR) of the work from Merz et al. [17]. In contrast to their work, in which verbal communication was varied, our study allows verbal communication and compares it with their conditions with verbal communication. By evaluating an asymmetric interaction between a smartphone and VR setup and comparing it with previous work, it becomes possible to assess whether smartphone-based participation, which is less immersive than desktop setups, further amplifies discrepancies in self-perception, other-perception, and task-perception. These findings can inform developers and researchers on how best to design platforms that allow for more inclusive and accessible applications and thus allow for asymmetric interactions.

2 Related Work

Following Slater's definition of immersion [26], it refers to an objective construct that describes to what extent a device can deliver an inclusive, extensive, surrounding, and vivid virtual environment. Plenty of prior research evaluated how different immersion levels affect key user experience indicators of self-perception (presence and embodiment), other-perception (co-, social presence, and virtual human plausibility), and task-perception (task load and task enjoyment).

2.1 Effect of Immersion on User Experience

A core element of self-perception in immersive experiences is the sense of presence, often described as the feeling of "being there" in the virtual world [24, 25]. High immersive devices can enhance sensorimotor contingencies, deepen this sense of presence, and improve the user experience [3]. Such devices also provide stronger visuomotor feedback, contributing to a stronger sense of embodiment [6] — the subjective experience of having and controlling a virtual body [11]. By contrast, desktop or smartphone-based participation provides a lower field of view, resolution, and motion tracking than HMD participation, which can decrease the sense of presence and embodiment [16].

Co-presence - the sense of being there together [22] - and social presence, which Biocca et al. [1] refer to as co-presence and psychobehavioral engagement with someone, are both key indicators of other-perception. They are often used to evaluate how successful social interaction is in emulating face-to-face communication [19]. Higher immersion leads to higher co-presence and social presence [17, 22]. Hence, more immersive devices are generally better for emulating face-to-face social interaction. An additional factor of other-perception is virtual human plausibility [13, 16]. Previous work has shown that immersion can affect how plausible users perceive virtual humans [14, 34].

In addition to self- and other-perception, task-perception is a key experience indicator for how effective an application is [9, 12]. A task is perceived as more demanding and less satisfactory when using less immersive devices [28, 29]. When the interaction possibilities remain equal across devices, less immersion can lead to lower usability [31].

2.2 Asymmetric Collaboration in Social XR

The results of previous works on immersion are central since, in an asymmetric interaction in XR, users participate with devices offering different levels of immersion [35]. Asymmetric interaction has become more frequent with the rise of commercial applications that support desktop- and smartphone-based participation alongside fully immersive HMDs. Previous research has proposed design strategies to address these disparities, such as adapting the interaction space, assigning device-specific roles, or simplifying controls for less immersed users [4, 20, 35]. However, implementing such role-based constraints might limit equitable participation in collaborative tasks that increase user experience [32]. While platforms such as Microsoft Teams, Meta Horizon, and Rec Room allow users to join shared virtual spaces using a wide range of hardware, they typically do not provide mechanisms for mitigating immersion differences. Recent research examined device-based asymmetry by comparing symmetric pairings of VR with an asymmetric one of VR and desktop users. Their results highlight how reduced immersion may lead to a diminished sense of self-perception and other-perception for the user with the less immersive setup, similar to what the basic results reported above suggest [16, 17]. However, additional studies are needed to assess whether even less immersive but currently frequently used devices, such as smartphones, impact self-perception, other perception, and task-perception.

2.3 Present Work

This study bridges the research gap by evaluating the possibility of balanced interaction with smartphone-based participation. This work builds on previous work [17] and uses the same methodology and is built with the same application, only adding support for smartphone devices to make the results of this study comparable with their condition. Based on related work on how different levels of immersion and asymmetric interaction affect user experience, we hypothesize the following:

Smartphone-based participation will lead to a:

H1: Lower feeling of presence compared to desktop participation (**H1.1**) and VR participation (**H1.2**).
H2: Lower perceived sense of embodiment compared to desktop participation (**H2.1**) and VR participation (**H2.2**).
H3: Lower perceived social presence compared to desktop participation (**H3.1**) and VR participation (**H3.2**)
H4: Lower virtual human plausibility compared to desktop participation (**H4.1**) and VR participation (**H4.2**).
H5: Higher task load compared to desktop participation (**H5.1**) and VR participation (**H5.2**)

3 Method

We conducted a between-subjects experiment to investigate the effects of smartphone participation in asymmetric interaction. Our experiment includes the asymmetric condition in which an HMD and controller-based VR user and a smartphone user collaborate. We then compare our results with the data from our previous work [17] that evaluated the asymmetric condition, in which a VR user collaborated with a desktop user, and one symmetric condition of two VR users. The implementation and study procedure are used from our previous work [17] to make that direct comparison between the conditions possible. This design allows comparisons between two asymmetric settings, in which one user is less immersed than the other user with the symmetric immersive setup of two VR users. Therefore, we have the following device pairings in which the normal text is the device of oneself and the subscript the devices of the interaction partner: S_{VR} - VR_{S} from our data collection, while D_{VR} - VR_{D}, and VR_{VR} - VR_{VR} is from Merz et al. [17].

3.1 Procedure

We invited two participants at the same time and placed them in separate rooms to ensure no direct visual contact. After reading the study's guidelines, the participants completed a consent form and some initial questionnaires (e.g., demographic data). Each participant then entered a private virtual environment, in which they learned the relevant interface to their assigned device and customized a stylized avatar. Then, they joined a shared virtual environment and performed a joint sorting task while communicating via voice chat. Once the task was completed, the participants completed the post-experiment questionnaires. Finally, the study ended with a short debriefing session and an opportunity for open-ended feedback.

3.2 System Description

The application was created with Unity 2021.3.15f1, integrating Photon's PUN2 for networking. A client-server architecture sends avatar states such as position and rotation at 20 Hz with lag compensation to ensure synchronized collaboration. Before entering the shared environment, participants could customize "ray-man style" avatars truncated at the hips, an approach chosen to avoid full inverse kinematics. In the VR condition, participants wore an HTC Vive Pro Eye with corresponding controllers for user input, and the headsets were tracked by two HTC Base Stations 2.0 per VR room. The smartphone was an iPhone 13 Pro Max. Participants in the VR condition used additional wired headphones, while participants in the Smartphone condition used similar headphones for consistent audio quality. The VR condition ran on a powerful Windows 10 to ensure consistent 90 frames, while the smartphone used iOS, resulting in 60 frames.

3.3 Task Design

The participants performed a sorting task that is replicated on the work by Merz et al. [16]. They sorted five objects by the number of corners. The task featured two colored tables, and each participant placed objects into semi-transparent containers above their table. One of the objects corresponded to the partner's color, and the participants had to transfer it using an interact button. Accepting the transferred object requires the partner to press the interaction button as well. When both participants finished sorting, each had to press the finish button to conclude the task. To ensure consistency across devices, the fundamental interaction remained virtual button-based. VR users pressed virtual buttons with their controllers and could look around naturally since the HMD was tracked. Smartphone users tapped the virtual buttons on their touchscreen and could swipe to rotate their viewpoint. This approach compared the interaction, isolating immersion as the main difference between smartphone and VR participants. We decided to use swiping to rotate the viewpoint since it is the most used interaction in current commercial applications.

3.4 Measures

We assess simulator sickness using the Simulator Sickness Questionnaire (SSQ) by Kennedy et al. [10], and immersive tendency, using Witmer and Singer's Immersive Tendency Questionnaire (ITQ) [33] as control variables.

For self-perception, we measured presence with the Igroup Presence Questionnaire (IPQ) [23] and assessed the sense of embodiment with the Virtual Embodiment Questionnaire (VEQ) [21].

Other-perception was captured using the Networked Mind Measurement (NMM) [1] for co-presence and social presence, along with the Virtual Human Plausibility (VHP) scale [13] and a single-item for perceived humanlikeness rated on a Likert scale of 1–7.

Task perception was evaluated through the Raw NASA Task Load Index (RTLX) [8]. Additionally, participants had to rate general usability and task enjoyment on a Likert scale of 1–7.

3.5 Participants

We had $N = 32$ participants, with a mean age of $M = 22.03$ ($SD = 2.36$) years. Seven were male and 25 female. All received credit points as part of their bachelor's degree. Both conditions S_{VR} and VR_{S} had $N = 16$ participants. We used the sample of previous work to compare our data with $N = 52$ participants. The conditions D_{VR} and VR_{D} had $N = 17$ participants, and VR_{VR} had $N = 18$ participants. Participants in that sample were $M = 20.29$ ($SD = 1.84$) years old, 48 were female, 3 were male, and 1 did not report a gender. The participants in both samples used their smartphones daily, while only 41% of the D_{VR} condition used a desktop computer daily. There were no significant differences between the previous VR experience and the conditions $\chi^2(16) = 13.06$, $p = .668$, or between the frequency of playing video games and the conditions $\chi^2(20) = 25.25$, $p = .192$, or between the frequency of using a desktop computer and the conditions $\chi^2(8) = 10.29$, $p = .245$. 83.3% of the participants had at least one hour of VR experience.

4 Results

We used Python 3.9. for data aggregation, score computation, and plot generation and R 4.4.0 for our statistical analysis. Our dependent variables showed violations of the normality and variance homogeneity. Therefore, we calculated nonparametric Kruskal-Wallis-Tests [15] with Dunn post hoc tests and applied the Holm correction for multiple pairwise comparisons. Table 1 shows the descriptive results for all our dependent variables.

4.1 Control Measures

Immersive tendency differed significantly between conditions, $F(4) = 28.65, p < .001$. Therefore, we validated all the results by calculating an ANCOVA, including immersive tendency as a covariate. The results of the ANCOVA show no significant effect of immersive tendency and a similar result for all our measurements. Simulator sickness showed significant differences from pre to post-measures, $F(4) = 71.66, p < .001$. However, the values were significantly lower for the post-measurement. Thus, we didn't take any further measures to rule out a potential confound.

4.2 Presence

As expected, spatial presence differed significantly between the devices, $H(4) = 30.21, p < .001$. Post hoc tests show lower spatial presence for S_{VR} ($z = 3.50, p < .001$) and D_{VR} ($z = 3.76, p < .01$) than for VR_{VR}.

Involvement also varied significantly as predicted, $H(4) = 14.70, p < .01$. Post hoc tests indicate lower involvement for D_{VR} compared to VR_{VR} ($z = 3.33, p < .01$).

Contrary to the expectation, realism did not differ significantly, $H(4) = 2.88, p = .579$.

4.3 Sense of Embodiment

Ownership differed significantly between devices confirming our hypothesis, $H(4) = 17.58, p < .01$. Post hoc comparisons show lower ownership for S_{VR} ($z = 3.14, p < .01$) and D_{VR} ($z = 2.62, p < .05$) than for VR_{VR}.

Agency had, as expected, a significant difference, $H(4) = 33.68, p < .001$. Post hoc tests reveal lower agency for S_{VR} ($z = 4.11, p < .001$) and D_{VR} ($z = 3.78, p < .001$) than for VR_{VR}.

Perceived change did not differ significantly between conditions, $H(4) = 9.07, p = .059$.

4.4 Co-Presence and Social Presence

Unexpected, co-presence self $H(4) = 1.15, p = .886$ and co-presence other $H(4) = 0.39, p = .983$ did not differ significantly.

As assumed, psychobehavioral engagement self varied significantly between devices, $H(4) = 11.33, p < .05$. Post hoc comparisons show lower psychobehavioral engagement self for D_{VR} than for VR_{VR} ($z = 3.18, p < .01$).

Psychobehavioral engagement other also differed significantly as hypothesized, $H(4) = 14.58, p < .01$. Post hoc tests indicate lower psychobehavioral engagement other for D_{VR} compared to VR_{VR} ($z = 3.75, p < .001$).

4.5 Virtual Human Plausibility and Humanlikeness

Unexpectedly, appearance behavior plausibility did not differ significantly, $H(4) = 5.37, p = .251$. The match with the virtual environment also did not show a significant effect $H(4) = 1.55, p = .818$. Humanlikeness did not show significant differences between the device configurations, $H(4) = 3.40, p = .493$.

4.6 Task Load

Mental demand differed significantly between the devices, $H(4) = 9.72, p < .05$. However, contrary to our expectations, post hoc comparisons show lower mental demand for S_{VR} than for VR_{VR} ($z = 2.75, p < .05$) and for S than for D ($z = 2.22, p < .05$).

In contrast to our assumption, the other task load scales did not show a significant effect: Physical demand $H(4) = 8.19, p = .085$, frustration $H(4) = 2.92, p = .572$, temporal demand $H(4) = 8.34, p = .080$, performance $H(4) = 1.42, p = .841$, and effort $H(4) = 4.91, p = .296$.

4.7 Task Enjoyment and Usability

In contrast to our expectation, task enjoyment did not differ significantly between devices, $H(4) = 8.19, p = .085$, and usability also did not show a significant effect, $H(4) = 3.67, p = .453$.

5 Discussion

Our study collected data on an asymmetric interaction between a smartphone user and a VR user. We then evaluated our results together with data from related research [17]. Our findings confirm **H1.1** and **H2.1** partially that smartphone-based participation leads to reduced self-perception in virtual environments compared to fully immersive HMDs, as seen in lower scores for spatial presence and lower sense of embodiment (ownership and agency) for smartphone users than for the VR users. The only exception is the embodiment subscale change, for which one would not expect any change in this experiment either. The results of **H1.1** are in line with previous work indicating that higher immersion supports stronger sensorimotor contingencies and more pronounced feelings of being there and owning and controlling a virtual body [11, 16, 24]. The reduced surroundings of smartphone users, which are based on the lower field of view, appear to weaken their sense of spatial presence. Additionally, smartphones allow for less visuomotor synchrony as body movements are not tracked, which lead to a lower sense of embodiment than in the VR condition, supporting our hypotheses on self-perception (**H2.1**. Interestingly, while spatial presence was significantly lower for smartphone users than for VR users, there was no corresponding significant decrease in involvement for smartphone participants, in contrast to desktop users. This might suggest that certain aspects of engagement remain intact even with lower immersion, possibly due to smartphone familiarity or the simplicity of the input interaction with smartphones.

Significant differences in other-perception were restricted to desktop participants, who showed lower psychobehavioral engagement compared to HMD users as shown in previous work [5, 17]. The present study reveals that smartphone participants did not exhibit significant reductions in co-presence or social presence compared to VR. Merz et al. [17] have found that participation at

			S_{VR}	D_{VR}	VR_{S}	VR_{D}	VR_{VR}
Measure	Range	Subscale	N=16	N=17	N=16	N=17	N=18
IPQ	0–6	Spatial Presence	3.45 (1.58)	3.82 (1.12)	5.51 (0.72)	5.25 (1.02)	5.40 (0.65)
		Involvement	4.61 (1.42)	3.56 (1.27)	4.67 (0.92)	5.15 (1.07)	5.08 (1.51)
		Realism	3.50 (0.84)	3.78 (0.55)	3.80 (0.71)	3.91 (0.74)	3.69 (0.53)
VEQ	1–7	Ownership	1.83 (1.02)	2.09 (1.22)	2.81 (1.45)	3.37 (1.47)	3.38 (1.51)
		Agency	3.23 (1.82)	3.71 (1.46)	5.80 (0.93)	5.50 (1.03)	5.74 (1.02)
		Change	1.91 (1.80)	2.26 (2.06)	2.92 (1.57)	3.03 (1.54)	2.60 (1.83)
NMM	1–7	CP self	4.12 (0.65)	3.79 (0.66)	4.09 (0.36)	4.00 (0.79)	3.94 (0.48)
		CP other	3.81 (0.32)	3.85 (0.73)	3.66 (0.83)	3.84 (0.36)	3.88 (0.42)
		PE self	3.90 (1.16)	3.26 (0.85)	3.92 (0.86)	3.67 (0.80)	4.23 (0.87)
		PE other	3.91 (1.13)	3.01 (1.16)	3.94 (0.93)	3.73 (1.00)	4.41 (0.96)
VHP	1–7	ABP	4.94 (0.95)	5.13 (0.94)	5.43 (0.63)	5.08 (0.93)	5.55 (0.68)
		MVE	5.89 (0.99)	5.82 (0.98)	6.02 (0.87)	5.85 (0.99)	6.18 (0.72)
Item	1–7	Humanlikeness	4.94 (2.11)	4.00 (2.26)	4.75 (1.65)	4.71 (1.53)	5.17 (1.65)
RTLX	0–100	Mental dem.	22.81 (17.41)	40.88 (21.81)	41.25 (16.48)	40.29 (22.53)	43.06 (18.88)
		Physical dem.	5.31 (8.65)	13.24 (16.58)	10.94 (9.17)	16.18 (17.28)	13.89 (13.23)
		Frustration	20.62 (21.05)	19.71 (13.86)	21.25 (16.48)	36.47 (30.86)	21.67 (17.06)
		Temporal dem.	8.44 (10.76)	20.00 (16.58)	28.75 (24.80)	27.06 (25.31)	25.83 (20.67)
		Performance	30.94 (25.25)	35.59 (26.74)	35.94 (27.03)	40.88 (28.08)	31.67 (24.97)
		Effort	13.44 (11.65)	24.71 (16.53)	22.19 (16.83)	23.53 (24.92)	30.56 (24.37)
Item	1–7	Usability	4.75 (1.91)	4.59 (1.50)	4.31 (1.89)	3.82 (1.78)	5.00 (1.19)
		Task enjoyment	5.00 (1.71)	5.12 (1.11)	5.81 (1.05)	5.82 (1.01)	6.00 (0.77)

Table 1: Means and standard deviation across the five device setups for all our dependent measurements.

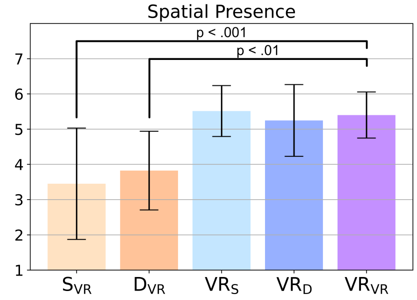

Figure 2: Means and standard deviations for spatial presence.

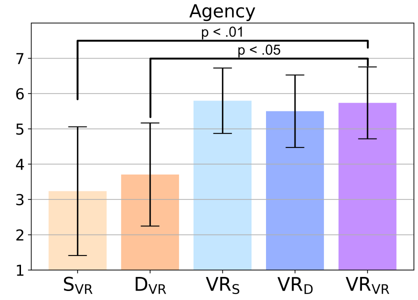

Figure 3: Means and standard deviations for perceived agency.

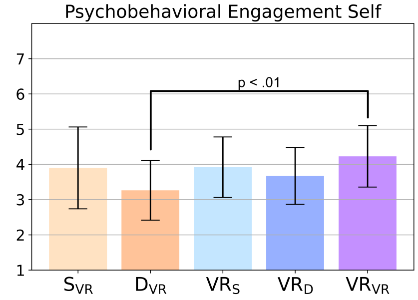

Figure 4: Means and standard deviations for psychobehavioral engagement self.

a lower level of immersion (desktop versus VR) has led to an impairment of other-perception. This also suggests that the degree of immersion is not the only determining factor but that familiarity and intuitive usability (as with a smartphone) could play a compensatory role.

Task-related measures did not indicate an increase in mental demand for smartphone users. In fact, smartphone participants reported lower mental demand than VR users and desktop users, which diverges from previous assumptions that lower immersion increases cognitive effort [4]. This finding may again reflect the smartphone interface's more familiar mechanics. Users simply tap and swipe, facing fewer complexities than those handling VR controllers or managing a desktop with a mouse.

Taken together, these results highlight that smartphone-based asymmetric collaboration can negatively impact key self-perception constructs, particularly the spatial presence and sense of embodiment, but may not universally diminish other-perception or task-perception. Notably, the similar level of social presence from smartphone users to VR users is particularly interesting as smartphones have lower immersion than desktop computers, but the descriptive values show higher social presence for the smartphone condition than for the desktop condition. Smartphones are widely used for connecting and maintaining interpersonal relationships [2]. Users' habit of using smartphones to communicate with others appears to have a top-down effect that overshadows the bottom-up incongruencies of low immersion. Therefore, we argue that smartphones have great potential for asymmetric interaction as they appear to be effective for social interaction and, at the same time, highly accessible. As asymmetric interaction continues to expand within commercial platforms, it seems more appropriate for users to participate through their smartphones than via desktop computers.

5.1 Limitations & Future Work

Our study compared smartphone-based participation only to VR and desktop setups using a single interaction paradigm. Future investigations might incorporate additional device configurations or more diverse interaction metaphors, especially those that involve more spatial information. For future work, it is important to evaluate more realistic scenarios in which voice chat and nonverbal cues play a larger role, which may provide a fuller picture of how device discrepancies shape collaboration in everyday use cases like in a negotiation task used in [30]. We decided to use swipe gestures to rotate the viewpoint and followed the implementations of commercial applications. In previous work of handheld social virtual collaboration, researchers used the gyroscope sensor for rotation [7, 18]. Future work could look into how these different methods compare to each other to get a deeper understanding of how to design handheld social XR applications. We used only single items for task enjoyment, usability, and humanlikeness to get some understanding of how these factors were affected by our manipulation. To get a deeper understanding of these factors, future work can design studies that evaluate those while using validated questionnaires. Additionally, interviewing participants after the collaboration to get qualitative data could help get a deeper understanding of the dynamics of asymmetric interaction. Our sample was comprised mainly of students with a homogeneous background, which might limit the generalizability to other age groups or populations. Extending participant recruitment to include a more varied demographic profile would enrich our understanding of how smartphone-based asymmetric interactions scale across different user backgrounds.

6 Conclusion

This work is the first evaluation of smartphone-based participation in asymmetric interaction in virtual environments, comparing it to desktop and VR asymmetry and symmetric VR setups. While smartphone users experienced a diminished sense of spatial presence and sense of embodiment, other key factors, such as social presence or task load, did not significantly decrease. In contrast to desktop-based participation, smartphones provided certain advantages: users experienced less mental demand and did not report lower social presence than users in the symmetric VR condition. Although some self-perception factors suffer compared to VR HMDs, smartphone users still achieve an overall engaging social experience with effective communication. These findings highlight the viability of smartphones as a less immersive but highly accessible option for participating in virtual environments and provide a good basis for designers and providers to improve the design of social experiences, even with low-tech solutions.

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