Universal Access for Social XR Across Devices: The Impact of Immersion on the Experience in Asymmetric Virtual Collaboration

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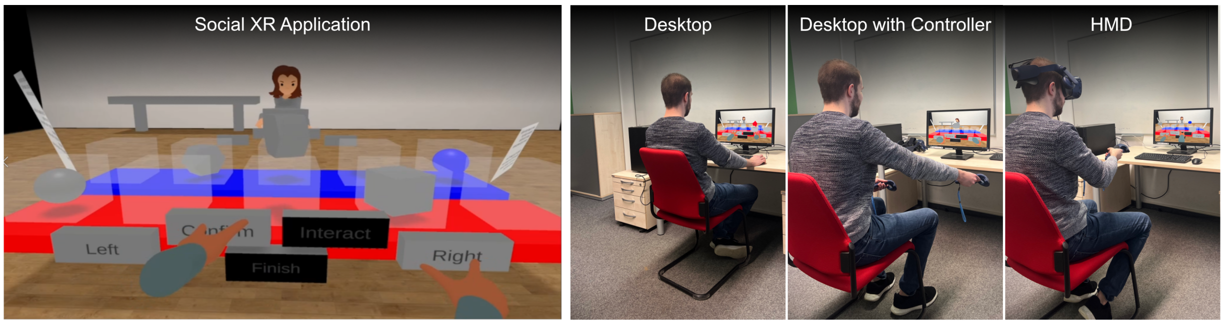

Figure 1: On the left is the participant's view of our social XR application. On the right are the three different device configurations of our study: desktop screen with mouse, desktop screen with VR controllers, and HMD with VR controllers.

Abstract

This article investigates the influence of input/output device characteristics and degrees of immersion on the User Experience (UX) of specific eXtended Reality (XR) effects, i.e., presence, self-perception, other-perception, and task perception. It targets universal access to social XR, where dedicated XR hardware is unavailable or can not be used, but participation is desirable or even necessary. We compare three different device configurations: (i) desktop screen with mouse, (ii) desktop screen with tracked controllers, and (iii) Head-Mounted Display (HMD) with tracked controllers. 87 participants took part in collaborative dyadic interaction (a sorting task) with asymmetric device configurations in a specifically developed social XR. In line with prior research, the sense of presence and embodiment were significantly lower for the desktop setups. However, we only found minor differences in task load and no differences in usability and enjoyment of the task between the conditions. Additionally, the perceived humanness and virtual human plausibility of the other were not affected, no matter the device used. Finally, there was no impact regarding co-presence and social presence independent of the level of immersion of oneself or the other. We conclude that the device in social XR is important for self-perception and presence. However, our results indicate that the devices do not affect important UX and usability aspects, specifically, the qualities of social interaction in collaborative scenarios, paving the way for universal access to social XR encounters and significantly promoting participation.

Keywords: VR, XR, social VR, immersion, co-presence, social presence, asymmetric collaboration, dyadic

Index Terms: Human-centered computing—Collaborative and social computing—Empirical studies in collaborative and social computing—;

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1 Introduction

Video conferencing provides mediated human-human interaction and collaboration while trying to retain important face-to-face communication signals. The COVID-19 pandemic has seen a surge of remote meetings from work to the private sphere. Accordingly, conventional meeting platforms like Zoom or Microsoft Teams have become well-established. However, despite their widespread use, conventional video-based conferencing platforms still fall short of replicating the richness and subtleties of physical face-to-face encounters missing critical body-related, spatial, and hence social cues. Several technologies of Virtual, Augmented, and Mixed Reality (VR, AR, MR: XR for short) provide an increased immersion [55]. They combine various multimodal displays with an extended sensory coverage of users, i.e., they provide motion-, face- and eye-tracking capabilities. Used to increase the 3D reconstruction accuracy of users' avatars in shared virtual spaces [24,42], they unlock important social cues and provide realistic spatial references [68], effectively providing the basis for a significantly extended human-human interaction in a social XR. For example, Smith and Neff have shown that communication in high-immersive VR is similar to face-to-face verbal and nonverbal communication [56]. Still, challenges like discomfort during extended sessions [64], locomotion limitations [4], cybersickness [57], and isolation from the real world need to be addressed to increase participation in social XR. Particularly important in the context of the work described here, access to specific XR devices might be restricted for multiple reasons, including users' location and surroundings, space limitations, medical considerations, or mere hardware availability.

To mitigate or overcome the dependency on specific XR hardware, participation in social XR can also be provided via less immersive devices like desktops or smartphones. Asymmetric interaction [74] allows users experiencing low immersion (e.g., using desktop or smartphone devices) to join a social XR while keeping the advantages of high immersive setups with, e.g., HMDs and diverse tracking devices, for other users where possible. However, the potentially resulting asymmetry might significantly affect the overall interaction quality, collaboration, and UX for all peers [11, 12, 33]. There is evidence for a positive effect of the feeling of working together on a task on user satisfaction and social presence [70] when the available forms of interaction between symmetric peers are balanced and not restricted. Yet, restrictions by specific roles or interactions for each device in asymmetric (remote) collaboration are proposed [18,20]. Overall, there is a noticeable gap regarding a systematic evaluation of the impact of asymmetric settings on the overall experience, which summarizes as follows:

RQ: How do different device characteristics and levels of immersion affect the self-perception, other-perception, and user satisfaction in an asymmetric collaborative social XR?

Contribution: To answer the research question, we developed a social XR environment that enables asymmetric interaction and collaboration between users. Two physically remote users collaborate in one virtual space with different interaction devices: (i) desktop screen with mouse, (ii) desktop screen with VR controllers as input, and (iii) HMD with VR controllers. In a user study with 87 participants, we compare these different interaction devices and how their provided levels of immersion affect self-perception (i.e., embodiment), the perception of others (i.e., social presence), user satisfaction (i.e., task load), and task perception (i.e., task enjoyment). Therefore, we evaluated the impact of users joining a social XR with different devices and how the differences in device characteristics and immersive capabilities influence the perception of the collaboration. Our results indicate that, although devices do have an impact on self-perception, they do not affect the perception of others or the overall collaborative experience. Hence, this work contributes the stepping stone for systematically evaluating the potential of integrating highly immersive technologies with less immersive devices to enhance remote collaboration. This underscores the capacity of social XR to facilitate more effective remote collaborative interactions compared to conventional video conferencing tools.

2 Related Work

Milgram et al. [36] introduced the reality-virtuality continuum regarding the differences in the immersion, which Skarbez et al. [53] revised and highlighted three different dimensions, namely the extent of world knowledge, immersion, and coherence. When manipulating the control and the display, we manipulate only the dimension of immersion as defined by Slater and Wilbur [55] as "the extent to which the computer displays are capable of delivering an inclusive, extensive, surrounding and vivid illusion of reality to the senses of a human participant". Therefore, immersion is a construct that is not subjectively measured through the participant but an objectively comparable one. Thus, different levels of immersion can be systematically varied experimentally. This is increasingly important in current technological developments and the growing distribution of XR applications and use cases. Invariably, users participate in shared virtual interactions with devices that differ in immersion level. In addition, one's degree of immersion (e.g., how does one participate in the XR interaction) has to be distinguished from the degree of immersion of the interaction partners (how do they participate). Therefore, evaluating the interaction partner or the interaction itself is particularly essential when manipulating the immersion of the other. The work from Latoschik et al. [25] supports this since their evaluation showed that the appearance of the other in social XR can influence self-perception.

2.1 Asymmetric interaction

Ens et al. [8] refers to asymmetry when users with different roles or capabilities collaborate. Others refer to users collaborating with different types of devices as asymmetric interfaces [40]. We refer to asymmetric interaction when users with different device configurations and, therefore, varying immersion collaborate in a social XR [74]. Previous studies have recognized the different participation requirements for remote asymmetric virtual interactions and proposed solutions to compensate for the different immersion levels [8,43,74]. In prior works, authors tried to reduce the interaction space of the less immersed user or tailor interaction possibilities of the less immersed user to a specific role [18,20,27,44].

However, there are many commercial asymmetric social XR applications like RecRoom [46], Mozilla Hubs [37] or Engage [7] that allow users to interact and collaborate independently of their devices without dedicated roles or other compensation methods. These relatively new asymmetric commercial applications thus lead to users participating with different degrees of immersion (self and other) on the one hand but using the same virtual space, performing the same tasks and interactions on the other. Hence, the question arises whether the degree of immersion (self or other) leads to a different experience in asymmetric social XR or whether the experience is similar between all participants. Asymmetric collaboration can be an effective tool for collaboration [62,66]. However, to date, there is a lack of studies that systematically investigate the impact of different levels of immersion in an asymmetric social XR collaboration with equal roles on UX [8]. To bridge this gap, our study investigates this issue concerning the following experience indicators, which are typically used for the evaluation of social VR collaborations [26,69]:

- Presence [41,58,60] as an basic indicator for different immersion levels
- Sense of embodiment [47] as an indicator for self-perception
- Plausibility [26,54], co-presence, social presence [76] and perceived humanness [17] of the other as indicators for other-perception
- Task load [14], task enjoyment and usability [31] as indicators for user satisfaction and task perception

2.2 The Impact of Immersion on Presence

The degree of immersion is strongly related to the feeling of spatial presence [53]. It is referred to as the "sense of being there" or the place illusion [55], which depends on the sensorimotor contingencies provided by the VR system. Recent theories support the link between immersion and presence and suggest that immersion, in particular, represents a bottom-up incongruence, which then leads to an impaired sense of spatial presence [26,53,54]. Changing the control and display of the device, and thus the immersion, in turn, changes the congruence at the sensation level.

Given the previous work and theoretical paradigms, presence is a crucial indicator for different degrees of (self) immersion. In other words, presence serves as a manipulation check for the immersion manipulation of oneself. Consequently, we assume:

H1: Lower self-immersion will lead to a lower reported feeling of spatial presence in asymmetric social XR.

2.3 The Impact of Immersion on Sense of Embodiment

A significant advantage of social XR compared to video conferencing is the interaction with a body in space. Therefore, avatars create a sense of embodiment in almost all (commercial) social XR applications. The latter is the sense of having a virtual body in a virtual environment (VE) consisting of the user's sense of self-location, agency, and body ownership [22]. Visuomotor synchrony and having motor control of the virtual body are crucial for the sense of agency [10]. Consequently, in asymmetric systems, having lower visuomotor synchrony provided by the input of the device should lead to lower perceived embodiment. Previous work confirms this since, similar to the sense of spatial presence, the perceived embodiment is also influenced by the level of (self) immersion [5]. Thus, embodiment serves as an indicator of the self-perception in our task. We assume that:

H2: Lower immersion of oneself will lead to a lower reported sense of embodiment in asymmetric social XR.

2.4 The Impact of Immersion on Co-Presence and Social Presence

The feeling of "being there together" is called co-presence [49]. Co-presence is described as mutual awareness of others and their actions [23]. Biocca et al. [3] used co-presence and psychological and behavioral engagement with the other to define social presence. Several studies linked social presence to positive communication outcomes, trust, and enjoyment [15,28], showing that social presence is an essential indicator for the perception of virtual collaboration. Others showed that co-presence and social presence also rely on the degree of immersion [1,50]. Using an HMD leads to a generally higher co-presence than using a desktop computer [50]. Furthermore, social presence increases when using stereoscopy, indicating high immersion [1]. Thus, co-presence and social presence are crucial indicators for the perception of others in a collaborative task. Since mutual perception plays an important role here, we suspect an influence of one's degree of immersion and others's degree of immersion. These previous findings lead to the hypotheses that:

H3.1: Lower immersion of oneself will lead to a lower perceived co-presence and social presence in asymmetric social XR.

H3.2: Lower immersion of the other will lead to a lower perceived co-presence and social presence in asymmetric social XR.

2.5 The Impact of Immersion on Virtual Human Plausibility

In addition to the sense of presence, the perception of plausibility is a vital evaluation parameter for the quality of XR experiences [26,54]. Mal et al. [32] have shown that virtual human plausibility is an essential factor in evaluating the perception of others in social XR. Wolf et al. [73] showed immersion affects virtual human plausibility ratings. Thus, virtual human plausibility is another critical indicator for the perception of others in a collaborative task. Since mutual perception plays an important role here, we suspect an influence of one's degree of immersion and an influence of the other's level of immersion. Consequently, we expect:

H4.1: Lower immersion of oneself will lead to a lower perceived virtual human plausibility of the other in asymmetric social XR.

H4.2: Lower immersion of the other will lead to a lower perceived virtual human plausibility of the other in asymmetric social XR.

2.6 The Impact of Immersion on Task Perception and Usability

Evaluating usability and task perception in XR gives insight into the effectiveness of the application [14,31]. Lower immersion leads to lower perceived usability when keeping the input metaphor identical [67]. The task is perceived as more demanding and less satisfactory when using devices with lower immersion [59,61]. Therefore, we hypothesize the following:

H5.1: Lower immersion of oneself will lead to a higher perceived task load and lower usability and task enjoyment in asymmetric social XR.

H5.2: Lower immersion of the other will lead to a lower perceived task load, usability, and task enjoyment in asymmetric social XR.

2.7 Summary and Present Work

In summary, numerous findings and current theories show that immersion tremendously impacts various indicators of experience in social XR. Previous work quite uniformly shows that a lower degree of immersion leads to a lower quality of experience. Therefore, compensation of the user interaction has often been sought for asymmetric social interactions. However, current tools and use cases only sometimes allow such compensation. However, they allow people to be in the same virtual space and participate equally in completing tasks. Thus, the question arises of whether this shared experience (top-down impact) can counteract the effects of different degrees of immersion (bottom-up impact). Furthermore, none of the studies to date systematically distinguishes the extent to which one's degree of immersion has an effect compared to the degree of immersion of the interaction partners. To address these gaps, our study examines the effects of different levels of self and other immersion in an asymmetric social XR collaboration on established UX indicators.

3 Method

3.1 Study Design

In a between-subjects design, we evaluate the influence of three different levels of immersion. In ascending order of immersion, we selected the conditions standard desktop setup with mouse input D, a flat-screen panel with VR controllers as input modality DwC, and a standard VR setup with HMD and controllers VR as our highest level of immersion condition. Therefore, our study consists of one condition with three levels manipulating immersion in a between-subjects design. Fig. 1 shows the study setup with the three different device configurations. We measured the distance for the D and DwC conditions, and in both conditions, participants were equally far from the screen.

We decided on a dyadic design to observe the effect of immersion in a social VE. We manipulate one participant's immersion while keeping the other's immersion constant. Since most state-of-the-art social XR consumer applications and previous work focused on embodied social VR, one participant always joins the social XR with a VR setup. This allows us to compare the effect of immersion on oneself and the effect of immersion on the other, leading to three different pairings shown in Table 1 with their coding. Since both participants in the first pairing (VR_{VR}) have the same device, our study setup consisted of five different codes. We only conducted half of the participants for VR_{VR} compared to the other two pairings to keep the group sizes equal.

3.2 Measures

Table 2 outlines the assessment of constructs in relation to specific hypotheses, specifying the questionnaires and questions used for measurement.

We measured immersive tendency [72] consisting of 18 items on a scale from 1 to 7, and simulator sickness [21] consisting of 14 items on a scale from 0 to 4 as control variables, since they are important factors to control for in XR evaluations [35,48].

To check if the immersion manipulation was successful (H1), we measured presence by the Igroup presence questionnaire (IPQ) [51] with the subscales general presence, spatial presence, involvement, and realism with in total of 19 items on a scale from 0 to 6.

To measure self-perception in the form of the sense of embodiment and test H2, we used the virtual embodiment questionnaire (VEQ) [47], with the subscales of ownership, agency, and change consisting of 13 items in total on a scale ranging from 1 to 7.

We measured co-presence and social presence with the networked mind measurement (NMM) [3] to test H3.1 and H3.2. It consists of four subscales: perception of self and of the other co-presence and perception of self and of the other psychological engagement (PE), consisting of 34 items on a scale from 1 to 7. We measured the effects on VHP [32] and its subscales of virtual human appearance and behavior plausibility (ABP) and the virtual human's match to the VE (MVE) consisting of 13 items on a scale from 0 to 6 to test for H4.1 and H4.2. Additionally, we used a single item in which participants rated the perceived humanness of the other on a scale from 1 to 7.

Table 1: An overview of the used devices for the interaction partners of our three pairings and the resulting codes, where the subscript defines the condition of the other.

		Participant 1		
	Device	VR	DwC	D
Participant 2	VR	VR_{VR} VR_{VR}	DwC_{VR} VR_{DwC}	D_{VR} VR_{D}

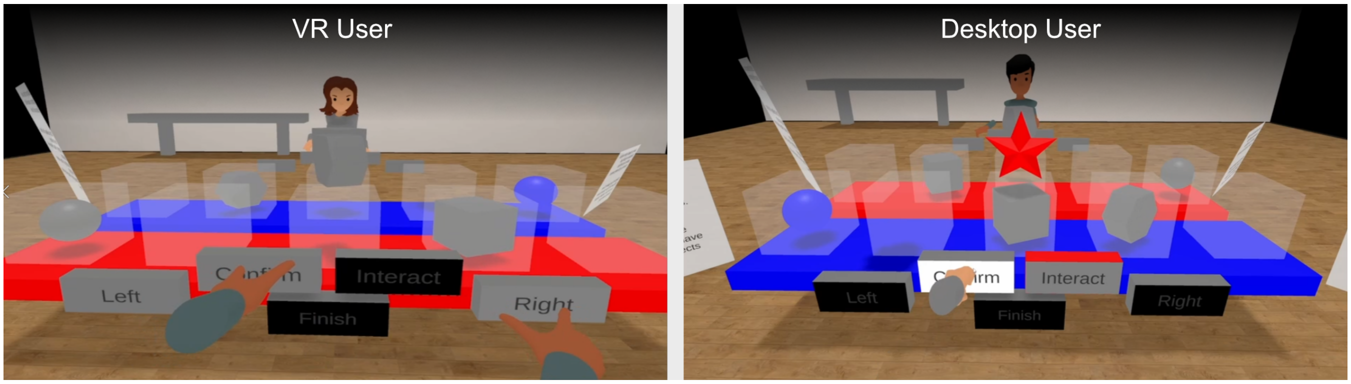

Figure 2: The respective points of view of a user with an HMD and controllers (VR) and a user with a desktop screen and mouse (D) during the collaborative sorting task in our dyadic study.

Table 2: Summary of the constructs we assessed with the corresponding hypotheses and measures.

Construct	Hypothesis	Variable	Measure
Control measurement	-	Simulator Sickness	SSQ [21]
	-	Immersive Tendency	ITQ [72]
Manipulation Check	H1	Presence	IPQ [51]
Self-perception	H2	Embodiment	VEQ [47]
Other-perception	H3.1, H3.2	Co-/Social Presence	NMM [3]
	H4.1, H4.2	Plausibility of other	VHP [32]
		Humanness of other	Single Item
User Satisfaction, Task Perception and Usability	H5.1, H5.2	Taskload	RTLX [14]
		Usability	Single Item
		Task Enjoyment	Single Item

We used the Raw NASA TLX (RTLX) to measure task load [13, 14], with its six subscales on a scale from 0 to 20 to test for H5.1 and H5.2. In addition, we used two single items where participants rated their enjoyment of the task and the general usability of the system on a scale from 1 to 7.

3.3 Hard- and Software

We developed our system in the game engine Unity3D version 2020.3.21f1 and used Photon's PUN2 architecture as a network component for the system. It is a client-to-server-based model that offers advantages over peer-to-peer architectures. The system transmits data from each client to the server in optimized packages at regular intervals, which the server then distributes to other connected clients for local processing. Our system sends information about the avatar configuration and the position and rotation data of the avatar's joints to the server at a refresh rate of $20Hz$ with lag compensation. Additionally, the client's task status is also sent to the server. In the system, participants can customize their avatar at the beginning of the experience, choosing between a female and a male stylized avatar. The customization options include the avatar's skin color, hair color, shirt color, and name. In the VE, avatars are displayed with the body cut below the hips and between the shoulders and hands (commonly known as "ray-man style") to avoid the use of inverse kinematic solutions for full-body animation, which is problematic with the sparse input of only three tracked devices [71]. Fig. 2 provides an example of the avatars displayed in the system. We used SteamVR version 1.14.15 with its Unity plugin to stream the tracking data of the HMD and the controllers into our application.

The VR condition used an HTC Vive Pro Eye HMD ($FoV = 110$ degree, refresh rate $= 90Hz$, resolution per eye $= 1440x1600$) with two Vive Pro Controllers. The DwC condition used a flat panel display with full HD resolution, 27" and $60Hz$ refresh rate, and two Vive Pro controllers as input. Condition D used a standard office mouse and the same flat panel display as DwC.

Two 2.0 HTC Base Stations track the VR components. The SteamVR tracking system offers rapid and accurate infrared-based tracking for various devices, such as HMDs, controllers, and additional trackers. It achieves a response time of 22 milliseconds, with a precision level that falls within a sub-millimeter range [39]. The system features a high sampling rate of $1000Hz$, which guarantees precise recording and capturing of device movements. We installed one pair of base stations in each experimental room and mounted them on tripods for stability. The outside-in tracking allowed us to track both controllers in the DwC condition and the entire VR setup in the VR condition. We used identical powerful computers with Microsoft Windows 10 consisting of an i7-11900K processor, an NVIDIA GeForce RTX 3080 GPU, and 64 GB DDR5-RAM for both study setups.

3.4 Procedure

We invited two participants to our study in different rooms at the same time. Each participant was picked up by an experimenter who led them to different experimental rooms. Our experiment followed the structure in Fig. 3. The participants first filled out a participation confirmation form and read the information regarding the study procedure. Afterward, the participants filled in the pre-questionnaires. Then, the participants entered the VE with their respective devices. In the private VE, the participants learned how to interact with the system and designed their avatars according to their preferences. When both participants finished this step, they joined the social environment. Then, the two participants had to solve a sorting task together. After the task, the participants filled in the post-questionnaires, and the experimenters bid farewell to their respective participants. To facilitate a study process as equally as possible, we ensured that the different steps started simultaneously for the pairs of participants. On average, the whole experiment lasted 35 minutes.

3.5 Task and System Interaction

In the study, the participants solved a sorting task together. Fig. 2 shows the perspective of the two participants on the task simultaneously. The lower half of the Fig. 3 shows the sequence of the sort task the participants had to solve during the study. Participants stood at a colored table, blue or red, each with five nearly transparent containers. They had to sort five items into the containers from left to right with an increasing number of corners. We chose these tasks because participants do not need special skills or have special prior knowledge to solve the task. Further previous work used sorting tasks when evaluating different device configurations [38]. First, an object spawns on top of the middle container. Then, participants can use the *Left* or *Right* button to move the object to another container. Pressing the *Confirm* button results in moving an object down into the container, and a new object spawns. One of the five objects has the color of their partner's table, and they must hand it over to their partner with the *Interact* button. Pressing the *Interact* button on one side changes the color of the *Interact* button from their partner, signaling they can accept the object. When the partner presses the *Interact* button, the object moves to the partner, who must sort the object into one of his containers. Then, a new object spawns. After sorting all five objects, the participant can press the *Finish* button. The task is solved when both participants press the *Finish* button. Buttons that cannot be pressed are colored in black.

When designing the interaction with the task for D, DwC, and VR, we had to ensure that the interaction with the system was as similar as possible. Thus, we hold the interaction paradigm with the task constant even if we change the input configuration by manipulating the immersion. We mediated the interaction with the system by pressing a button to ensure comparability. The D condition used the mouse to interact with the task. To interact with the buttons, the user clicks the virtual buttons with the left mouse button, then a pre-recorded animation moves the corresponding hand to touch the button. Holding the right mouse button down allows the user to look around in the VE by rotating the user's avatar and the corresponding view. We used the Vive controller as the input modality for the condition DwC. To interact with the task, the user has to move the controller to the virtual buttons. Pressing both trigger buttons of the Vive controller simultaneously and moving the controllers in the direction the user wants to look rotates the user view and avatar in the same direction. The VR condition used the Vive controller to interact with the task, and the interaction works the same way as in the DwC condition. However, the VR user can look around in the VE by moving the head.

3.6 Participants

We recruited 88 participants for our study, one participant was excluded because they did not correct their visual impairment during the experiment, resulting in $N = 87$. $N = 58$ were students who received credit points as part of their bachelor's degree, and $N = 29$ received money as compensation. The students had the same knowledge background of studying media and computer science. The condition D_{VR} and VR_{D} had $N = 18$ participants, and DwC_{VR}, VR_{DwC} and VR_{VR} had $N = 17$ participants. Our sample of $N = 87$ was $M = 23.69$ ($SD = 5.89$) years old. $70,1\%$ were female, 28.6% were male, and 1.2% did not report a gender. There were no significant differences between the gender and the condition $\chi^2(4) = 4.07$, $p = .397$, or between the prior experience and condition $\chi^2(20) = 19.59$, $p = .484$, or between the frequency of using a desktop computer and condition $\chi^2(16) = 17.31$, $p = .366$. 88.5% of the participants had at least one hour of VR experience.

4 Results

We used Python 3.8 for the data aggregation, score computation, and generating the plots. For our statistical analysis, we used JASP 0.17 [30]. Testing for the normality and variance homogeneity assumptions for the main measurements, we found multiple violations. Hence, we decided to use the nonparametric Kruskal-Wallis-Test [34] with multiple pairwise comparisons from Dunn with Bonferroni correction. To keep the probability of an alpha error as low as possible, we only report the results of the three (manipulation check and self-perception) or six pairwise comparisons (other-perception, user satisfaction, and task perception) shown in Table 3, that reflect our hypotheses. The control measures showed no assumption violations and were tested with ANOVA tests and corresponding post-hoc tests with Bonferroni corrections. Table 4 shows the mean and standard deviation for all dependent and control variables, excluding simulator sickness.

Table 3: All pairwise comparisons that we evaluated in our statistical analysis.

Comparison of the immersion of onself	Comparison of the immersion of the other
VR_{VR} vs. DwC_{VR}	VR_{VR} vs. VR_{DwC}
VR_{VR} vs. D_{VR}	VR_{VR} vs. VR_{D}
DwC_{VR} vs. D_{VR}	VR_{DwC} vs. VR_{D}

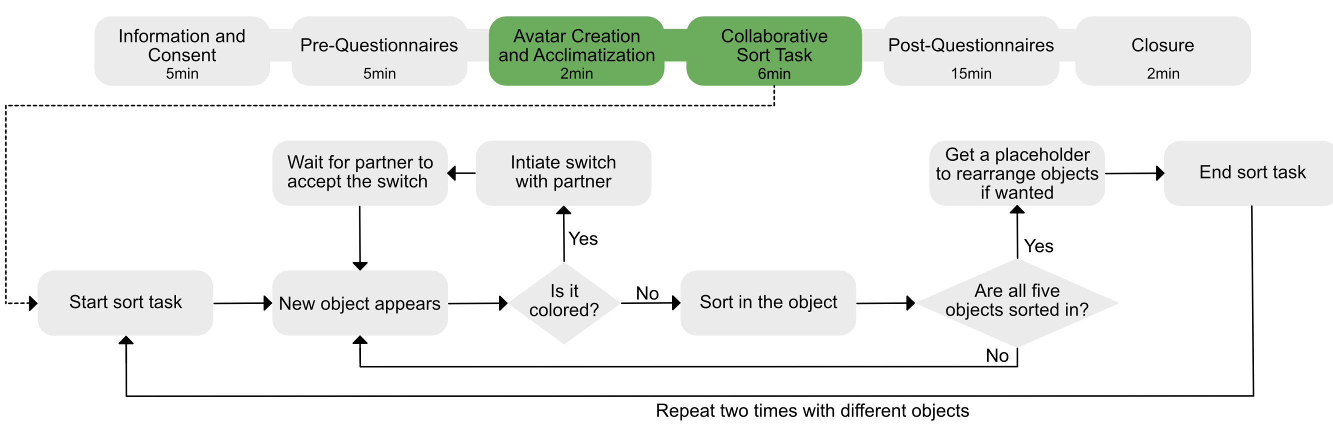

Figure 3: The upper part shows the procedure of our study, where green highlights the parts in the VE. The lower part shows the procedure of the sort task the participants had to solve during the study.

Table 4: Mean (M) and standard deviation (SD) of in total $N = 87$ participants for all subscales of the dependent measurements. $*\ p < .05$, $**\ p < .01$, $***\ p < .001$ for the nonparametric Kruskal-Wallis test.

Measure	Range	Subscale	D_{VR} $N = 18$ $M(SD)$	DwC_{VR} $N = 17$ $M(SD)$	VR_{VR} $N = 17$ $M(SD)$	VR_{DwC} $N = 17$ $M(SD)$	VR_{D} $N = 18$ $M(SD)$
IPQ	0 - 6	General presence $***$	2.36 (0.92)	2.56 (0.92)	3.44 (0.81)	3.01 (0.55)	3.73 (0.69)
		Spatial $***$	2.18 (1.32)	2.88 (1.32)	3.74 (1.14)	3.61 (0.85)	4.11 (0.97)
		Involvement $**$	2.63 (1.67)	2.29 (1.52)	3.54 (1.15)	2.40 (1.06)	3.75 (1.17)
		Realism $**$	2.54 (0.61)	2.56 (0.63)	2.91 (0.63)	2.79 (0.51)	3.22 (0.53)
VEQ	1 - 7	Ownership $***$	1.65 (1.08)	2.44 (1.15)	3.15 (1.23)	2.96 (1.26)	3.35 (1.28)
		Agency $***$	3.31 (1.70)	5.06 (0.90)	5.87 (1.06)	5.16 (1.17)	5.50 (0.65)
		Change $*$	1.44 (1.19)	2.47 (1.51)	2.28 (1.10)	2.04 (1.51)	2.35 (1.34)
NMM	1 - 7	CP self	3.88 (0.72)	3.79 (0.65)	3.82 (0.62)	4.07 (0.51)	3.86 (0.34)
		CP other	3.71 (0.85)	3.53 (0.47)	3.85 (0.50)	3.91 (0.41)	3.74 (0.66)
		PE self	2.74 (0.77)	3.16 (0.74)	3.09 (1.01)	2.83 (0.90)	3.00 (0.67)
		PE other	2.46 (0.95)	2.88 (0.74)	2.92 (1.20)	2.83 (1.08)	2.74 (0.79)
VHP	1 - 7	ABP	4.69 (0.85)	4.97 (0.61)	4.96 (0.49)	4.98 (0.83)	4.98 (0.56)
		MVE	5.74 (0.69)	5.65 (0.55)	5.57 (0.84)	5.44 (1.26)	6.07 (0.60)
Single Item	1-7	Humanness other	3.33 (2.03)	3.88 (2.45)	3.41 (1.73)	3.47 (1.74)	3.39 (1.82)
RTLX	0 - 100	Mental demand	38.06 (19.94)	43.82 (23.69)	40.88 (21.16)	52.06 (21.14)	36.94 (23.02)
		Physical demand $**$	6.39 (5.89)	21.18 (21.33)	10.88 (11.2)	19.71 (14.30)	15.00 (11.88)
		Frustration	30.00 (23.52)	40.88 (27.74)	29.12 (23.00)	40.00 (29.90)	31.11 (24.89)
		Temporal demand	32.50 (25.39)	35.00 (25.13)	25.00 (24.81)	30.88 (24.38)	28.89 (25.59)
		Performance	36.67 (25.50)	41.47 (17.39)	51.18 (23.15)	44.12 (18.14)	34.72 (20.47)
		Effort	25.28 (23.61)	33.53 (24.09)	23.82 (16.16)	30.29 (18.66)	28.89 (22.20)
Single Item	1 - 7	Usability	4.61 (1.42)	3.94 (1.52)	4.65 (1.37)	4.00 (1.49)	4.39 (1.50)
		Task enjoyment	5.28 (1.27)	5.77 (1.39)	5.41 (1.62)	4.59 (2.24)	5.17 (1.30)

4.1 Control Measurements

Since there were no violations regarding immersive tendency, we used a one-way between-subjects ANOVA to compare immersive tendency between the devices used, which showed no significant differences, $F(4,82) = .649, p = .629$.

Using a one-way between-subjects repeated measures ANOVA, we compared pre- and post-measurement of simulator sickness for the device used. We found significant differences regarding the pre-SSQ between at least two groups, $F(4,82) = 3.95, p = .006$. Bonferroni-corrected post hoc tests revealed a significant difference between VR_{DwC} and VR_{VR} ($p = .010$). The total score for the condition VR_{DwC} ($M = 44.88, SD = 28.61$) was significant higher than VR_{VR} ($M = 16.72, SD = 17.04$). Further, we found that the total scores for SSQ decreased in all five conditions from pre- to post-measurements, and there were no significant differences for post-SSQ.

4.2 Manipulation Check for the Immersion Manipulation Success

As expected, general presence was significantly affected by the device used (degree of immersion), $H(4) = 26.67, p < .001$. Pairwise comparison revealed that general presence is lower when using D_{VR} than when using VR_{VR} ($z = -3.26, p < .001$), and DwC_{VR} than when using VR_{VR}, $z = -2.79, p = .016$. This general result pattern was also reflected in the subscores of the presence questionnaire. Fig. 4 shows boxplots with the significant results marked.

The device used significantly affected spatial presence, $H(4) = 23.36, p < .001$. The pairwise comparison revealed that spatial presence is lower when using D_{VR} than when using VR_{VR}, $z = -3.42, p < .001$.

Realism differed significantly by the device used, $H(4) = 15.61, p = .004$. The pairwise comparison revealed no significant difference between the previously defined pairwise comparisons.

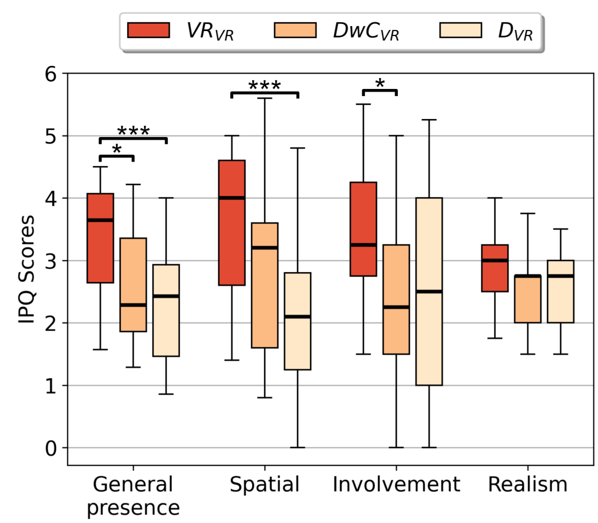

Figure 4: Perceived presence in dependency of immersion of oneself ($***\ p < .001$, $*\ p < .05$).

Involvement was significantly different for the device used, $H(4) = 15.28, p = .004$. Pairwise comparison revealed that involvement is lower when using DwC_{VR} than when using VR_{VR}, $z = -2.48, p = .039$.

4.3 The Impact of Immersion on Self-Perception

Ownership was significantly affected by the device used, $H(4) = 22.43, p < .001$. Pairwise comparison revealed that ownership is lower when using D_{VR} than when using VR_{VR}, $z = -3.76, p < .001$.

Agency was significantly affected by the device used $H(4) = 26.69, p < .001$. Pairwise comparison revealed that agency is lower when using D_{VR} than when using VR_{VR}, $z = -4.89, p < .001$, and lower when using D_{VR} than when using DwC_{VR}, $z = -2.60, p = .028$. There is a trend that agency is lower when using DwC_{VR} than when using VR_{VR}, $z = -2.26, p = .071$.

There was a significant difference when comparing the perceived change between the devices, $H(4) = 10.45, p = .034$. Pairwise comparison revealed that the perceived change is lower when using D_{VR} than when using VR_{VR}, $z = -2.63, p = .026$, and lower when using D_{VR} than when using DwC_{VR}, $z = -2.71, p = .020$. See Fig. 5 for boxplots with the significant results marked.

4.4 Impact of Immersion on Other-Perception

4.4.1 Co-Presence and Social Presence

There were no significant differences when comparing the co-presence of oneself between devices, $H(4) = 3.06, p = .549$, or co-presence of the other, $H(4) = 6.08, p = .193$.

Additionally, there were no significant differences when comparing the perceived psychological engagement of oneself between devices, $H(4) = 3.09, p = .543$, or psychological engagement of the other, $H(4) = 3.05, p = .550$. Fig. 6 and Fig. 7 show boxplots with descriptive values.

Since non-significant results of classical hypotheses tests do not mean that the null hypothesis is confirmed, we calculated a Bayesian ANOVA as described by van den Bergh et al. [63] to be sure that too little power did not lead to the non-significant results. We calculated the Bayes Factors (BFs) by comparing the model of interest (significant differences as assumed by the hypotheses) to a null model, which we then interpreted by the guide from Lee and Wagenmakers [29]. The Bayesian ANOVA showed strong evidence in favor of the null hypothesis for the subscale of co-presence of oneself ($BF_{01} = 10.20$) and moderate evidence for co-presence of the other ($BF_{01} = 6.02$). It also revealed moderate evidence in favor of the null model for the subscales of perceived psychological engagement of oneself ($BF_{01} = 8.00$) and the other ($BF_{01} = 9.43$). This indicates that the participants did not perceive a difference when we manipulated the immersion of oneself or the other regarding co-presence and social presence.

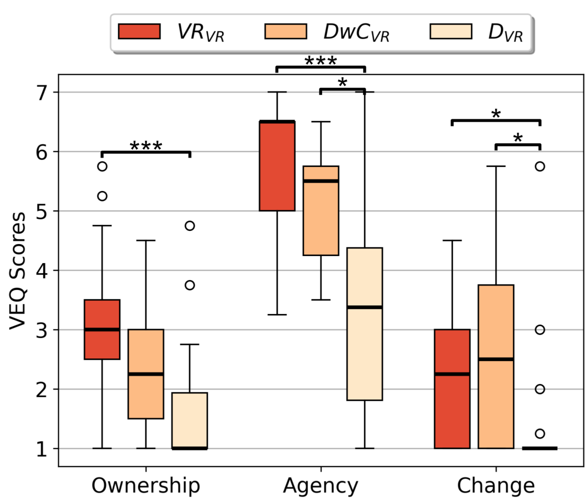

Figure 5: Perceived sense of embodiment in dependency of immersion of oneself ($***\ p < .001$, $*\ p < .05$).

4.4.2 Virtual Human Plausibility

There was no significant difference regarding the ABP of the other, $H(4) = 1.58, p = .812$, or the MVE $H(4) = 0.77, p = .943$.

As in Sect. 4.4.1, we calculated a Bayesian ANOVA to test for differences in VHP when manipulating immersion. It showed strong evidence in favor of the null hypothesis for ABP ($BF_{01} = 10.10$) and moderate evidence for MVE ($BF_{01} = 3.41$). This indicates no difference in the participants' perception of VHP when manipulating oneself or the other immersion. Fig. 8 and Fig. 9 show boxplots with descriptive values.

4.4.3 Perceived Humanness

There was no significant difference in the perceived humanness of the other, $H(4) = 0.77, p = .943$. The Bayesian ANOVA showed strong evidence that there was no difference when manipulating the immersion of oneself or the other ($BF_{01} = 16.69$).

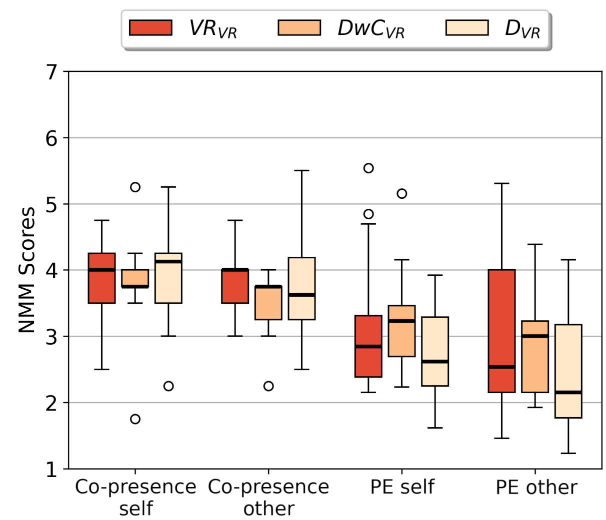

Figure 6: Perceived co-presence and social presence in dependency of immersion of oneself.

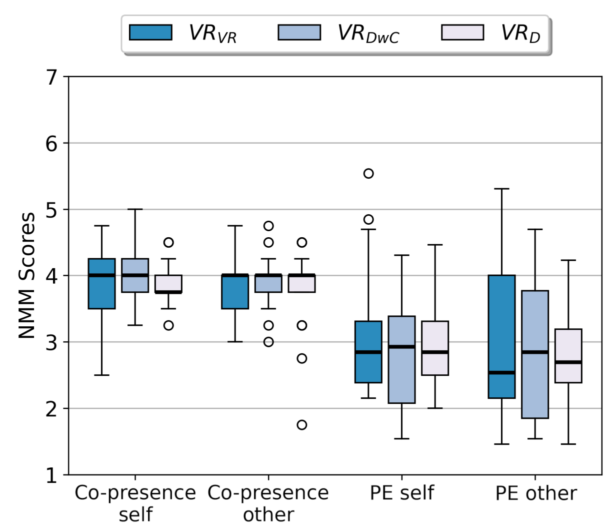

Figure 7: Perceived co-presence and social presence in dependency of immersion of the other.

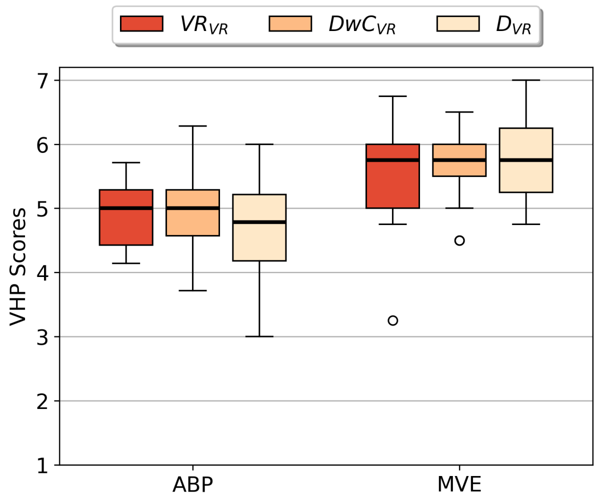

Figure 8: Perceived VHP in dependency of immersion of oneself for the scales of appearance and behavior plausibility (ABP) and match with the VE (MVE).

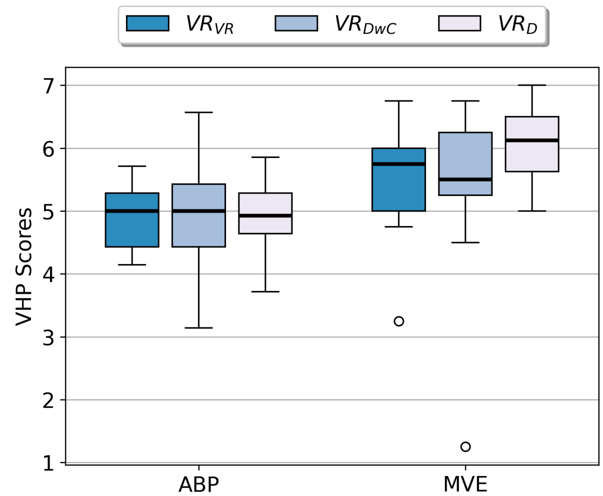

Figure 9: Boxplot of perceived VHP in dependency of immersion of the other for the scales of appearance and behavior plausibility (ABP) and match with the VE (MVE).

4.5 Impact of Immersion on User Satisfaction and Task Perception

4.5.1 Task Load

Comparing the reported mental demand between the devices showed no significant difference, $H(4) = 4.16, p = .385$.

There was a significant difference when comparing the physical demand between the devices, $H(4) = 13.67, p = .008$. Pairwise comparisons revealed that physical demand is lower when using D_{VR} than when using DwC_{VR}, $z = -2.76, p = .035$.

The reported frustration between the devices did not show significant differences, $H(4) = 2.68, p = .612$.

Comparing the reported temporal demand between the devices showed no significant difference, $H(4) = 2.03, p = .730$.

There were no significant differences between the devices used for perceived performance, $H(4) = 6.32, p = .177$, or perceived effort, $H(4) = 2.98, p = .562$.

The Bayesian ANOVA revealed that there was no difference for mental demand ($BF_{01} = 4.02$) and frustration ($BF_{01} = 7.52$) with moderate evidence for performance ($BF_{01} = 2.67$) with low evidence, and for temporal demand ($BF_{01} = 13.33$) and effort ($BF_{01} = 10.52$) with strong evidence.

4.5.2 Usability and Task Enjoyment

There was no significant difference in the usability of the system ($H(4) = 3.60, p = .462$) or task enjoyment between devices ($H(4) = 3.49, p = .480$). A Bayesian ANOVA revealed moderate evidence for the null hypothesis for perceived usability ($BF_{01} = 6.99$) or perceived task enjoyment ($BF_{01} = 4.63$), indicating that there was no difference when manipulating immersion.

5 Discussion

Our work evaluates the effect of immersion in an asymmetric collaborative social XR on self-perception, other-perception, user satisfaction, and task load. For oneself and the other, we manipulated immersion with three different device configurations: (i) desktop screen with mouse (D), (ii) desktop screen with controllers (DwC), (iii) and HMD with controllers (VR). This results in a manipulation of immersion for oneself or the other on several subfactors (e.g., field of view or input modality).

First, we found that the control measures of the immersive tendency and simulator sickness had no differential influence between the immersion conditions. Simulator sickness showed only a significant difference in the pre-measurement between VR_{DwC} and VR_{VR}. The simulator sickness scores decreased from pre- to post-measurement in all conditions, indicating that our application did not induce simulator sickness and, hence, was not confounding the experience even when wearing an HMD.

Furthermore, the manipulation check was successful, and H1 could be confirmed. Across the different presence subscales, the sense of presence was lower in low immersion conditions. This is consistent with previous literature that has shown that a smaller field of view, stereoscopic images, and reduced user tracking are the most important subfactors for impairing the sense of presence [5, 6, 52]. Therefore, we can transfer the findings that immersion affects the perceived presence of symmetric to asymmetric interaction,

Similar results were shown for self-perception, thereby confirming H2. The sense of embodiment, that is, the feeling of ownership, agency, and change, was lower in the low immersion conditions. This is also in line with previous literature, which has shown that lower immersion, specifically lower visuomotor synchrony, leads to a lower sense of embodiment [10]. Therefore, effects related to embodiment (e.g., choice of avatar, proteus effect [9, 45, 75]) could also be smaller for less immersed users in an asymmetric interaction.

Contrary to our hypotheses, no effects of the immersion manipulation (self or other) on other-perception were shown. Thereby we have to reject H3 and H4. We measured medium to high scores for copresence, plausibility, and perceived humanness regardless of the device used. In contrast, our results show low scores for social presence. These results are surprising as previous studies have found that copresence and social presence depend on the level of immersion [1, 50]. However, the low scores for social presence could be due to the lack of voice communication. In our study, we deliberately omitted verbal communication to evaluate the device-dependent differences with as few potentially confounding additional social cues as possible. Previous studies on asymmetric interaction have changed not only the device but also the interaction possibilities, leaving a research gap in evaluating device-dependent differences in asymmetric interaction [16, 20]. Thus, we deliberately excluded verbal communication systematically and investigated the potential impacts solely stemming from alternations in display and (non-verbal) interaction characteristics, which were modified to manipulate immersion. Since our conditions do not differ in principle in functionalities for verbal communication, it is not to be expected that verbal communication would have had a systematic influence on the results. Based on our results, we can conclude that the perception of the counterpart in an asymmetric virtual interaction does not depend on immersion level-based bottom-up incongruence alone [26]. The Bayesian ANOVA further ensures that the lack of significant differences is not due to low power. Therefore, while self-perception is affected by the change of immersion of oneself, there is no evidence that the perception of the other is affected. We conclude that asymmetric interaction can be an effective tool for collaboration when the interaction space is the same and users with less immersion are not limited or restricted in their own interaction possibilities. Since there was no difference for other-perception and the corresponding values for co-presence and plausibility were medium to high, we suspect that the social perception in an asymmetric interaction rather depends on top-down factors, e.g., interdependence, need for social interaction [70]. However, we can only assume this for interaction without additional social cues like verbal communication as they might alter the other-perception.

User satisfaction and task satisfaction were also not affected by the level of immersion. Only physical demand was higher for *DwC* than *D*. With the aspect that previous studies linked social presence to other positive communication outcomes, trust, and enjoyment [15,28], this is not surprising and is consistent with previous research [67]. So, it also seems rather important for the general evaluation of the application of the perceived quality of shared interaction, even if some bottom-up incongruencies occur. This strengthens our argumentation that the perception of the other and the interaction is not affected by the immersion in asymmetric settings. Indicating that we can use asymmetric settings to include users with different devices while not reducing the quality of the collaboration.

5.1 Limitations and Future Work

With the different device configurations for our conditions, we manipulated immersion on several aspects [55]. There is not only a change in the field of view between a desktop screen and an HMD but also in stereoscopy and occlusion of the real world. Therefore, the physical body can still be seen on the desktop screen. Replacing an HMD with a desktop screen also reduces the information of the user's actual position since the HMD tracks the user's head position and rotation. Therefore, the input differs regarding the tracking and in terms of the input metaphor. Hence, in our study, we compare only the device configuration in total, but we cannot break down our findings to the specific changes of specific immersion characteristics. However, our design is based on realistic conditions. People can join many digital collaboration platforms with different input devices, from which we have made a selection. We wanted to represent these as well as possible to make the results usable for practical application. For example, we have chosen the interaction with VR controllers in the condition *DwC* to reduce the variance of immersion manipulation as Jeong et al. [20]. The task in our VE only covered about 180° in front of the participants. Hence, spatial awareness was rather less necessary to solve the task. Further, the VE was rather primitive than colorful and rich, like in state-of-the-art applications. Therefore, our findings have to be confirmed for more complex environments and tasks in future studies. For example, previous work has shown that the device can affect tasks with more spatial interaction like 3D docking or 3D visualization tasks [2, 19, 65].

There are various possibilities to extend and build on this work, for example, by manipulating the immersion on specific sub-factors, leading to more specific findings regarding which one influences the UX the most. Future work could lower the immersion of one collaborator even more by evaluating the effect of a smartphone, which is already used by many video conferencing platforms and in general for social interaction, to get a broader understanding of how common-used devices impact social interaction and therefore the universal access for social XR. Further, our work acts as a basis for subsequent research investigating whether additional social cues, like verbal communication, would influence asymmetric virtual collaboration and whether there is an interaction effect with different immersion conditions. Additionally, future work can use our results as a baseline to investigate how factors like environmental design, locomotion techniques, or avatar appearance impact asymmetric social XR.

For observing the perceived humanness of the other, usability, and task enjoyment, we only used non-validated single items, which gives a first indication regarding those factors. Still, they lack validity and, therefore, have lower predictive power. As we have already investigated various factors, we decided not to use more common questionnaires with multiple subscales and items, as this would have further increased the duration of the experiment and the time between manipulation and questionnaires. Our participants had a homogenous knowledge background with unbalanced gender and do not represent the population. Hence, we can only extrapolate our results to the overall population to a limited extent.

6 Conclusion

In conclusion, our research carries implications for the design of immersive social XR environments with asymmetric interactions. We confirm previous findings that having higher immersion leads to a higher quality of self-perception. However, the perception of the other was not affected, so asymmetric social XR platforms are promising for further dissemination and inclusion. Our findings offer valuable insights for human-computer interaction researchers and designers seeking to create more accessible social XR environments. By highlighting the role of immersion in conjunction with top-down factors, we advocate for developing socially inclusive XR applications that cater to a wider range of users, including those with less immersive hardware or sensory limitations. Hence, we make advancements for future research to replace video conferencing platforms with universally accessible social XR. This work sets the stage for further exploration of the interplay between immersion and UX in asymmetric social XR, with the goal of paving the way for universal access and enhanced remote collaborative interactions that can provide effective communication like face-to-face.

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