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ORIGINAL ARTICLE

The presence of an avatar can reduce cybersickness in Virtual Reality

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Abstract
Virtual Reality (VR) applications are increasingly being utilized for research, healthcare, and education. Despite their benefits, many VR users report motion sickness-like sensations (cybersickness), such as headache, disorientation, or nausea. Previous studies suggest that the sense of presence ("being there") in the virtual world may contribute to the severity of cybersickness; however, results have been contradictory, with some studies reporting a negative and some reporting a positive relationship between the two. The goal of the current study was to further investigate how presence and cybersickness are related. Participants ($N=54$) were exposed to a VR scene presented on a head-mounted display showing a 15-minute-long passive movement through space. The level of presence was manipulated by including an avatar (astronaut suit with hand-tracking) or no avatar in the virtual environment. Results showed that the avatar group reported significantly less severe cybersickness compared to the no-avatar group. We also found significant, negative correlations between some of the presence metrics (immersion, sensory fidelity) and cybersickness, indicating that cybersickness severity decreased as the level of presence increased. These findings suggest that more immersive VR experiences using an avatar may potentially reduce the risk of experiencing cybersickness.

Keywords Motion sickness · Cybersickness · Virtual Reality · Presence · Avatar · Field dependence

1 Introduction

Today, Virtual Reality (VR) is commonly used for research, healthcare, training, education, and entertainment purposes. Although VR technologies have improved significantly since they were first introduced, *cybersickness* is still one common side effect for many individuals with premature termination rates of VR sessions being as high as 60% in some cases (Caserman et al. 2021; Rebenitsch and Owen 2016; Saredakis et al. 2020). Cybersickness (also referred to as VR sickness or, more generally, visually induced motion sickness) is a special form of motion sickness and entails a range of symptoms including nausea, dizziness, headache, eyestrain, cold sweats, and fatigue (Kennedy et al. 2010; Keshavarz and Golding 2022). A unique aspect of a VR experience is that it transports individuals to an alternate world, and the individual's sense of "being there" in that world is commonly referred to as a sense of *presence* (Heeter 1992; Slater and Steed 1994). Past studies that have explored the relationship between presence and cybersickness have led to contradictory results, with some finding a negative relationship, a positive relationship, or no relationship at all (see Weech et al. 2019 for a review). Thus, the present study aimed to further investigate how presence and cybersickness are linked to each other by systematically manipulating the level of presence via a self-avatar (avatar vs. no-avatar) and measuring its impact on self-reported cybersickness.

1.1 Presence and cybersickness

Various theories attempt to explain the underlying mechanisms resulting in cybersickness, including the role of postural control (Riccio and Stoffregen 1991), eye movements (Ebenholtz 1992), or, more recently, the role of unexpected

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self-motion illusions (Teixeira et al. 2022). One of the most prominent theories focuses on a sensory conflict between or within the visual, vestibular, and proprioceptive senses (Oman 1990; Reason and Brand 1975). Following this approach, incongruent information delivered by these senses may cause cybersickness when this sensory conflict is novel to the user and they have not habituated successfully to it (Reason 1978). For example, in a VR scene, the visual sense may convey the illusion of self-motion (or vection) (Berti and Keshavarz 2020; Palmisano et al. 2015), whereas the vestibular and proprioceptive senses signal stasis, which may result in cybersickness.

The severity of cybersickness can be influenced by various factors, including technological features (e.g., size of the field-of-view, time-lag;Bos et al. 2010; Draper et al. 2001; Keshavarz et al. 2011; Moss and Muth 2011), stimulus-related characteristics (e.g., scene complexity, navigation speed;So et al. 2001; Stanney and Hash 1998), or individual aspects (e.g., age, biological sex;Munafo et al. 2017; Stanney et al. 2020). In addition, the impact of other VR-related phenomena on cybersickness has been discussed in the past, including the roles of vection (Keshavarz et al. 2015) and presence (Weech et al. 2019). Specifically, given the substantial improvements of recent VR headsets and their high-fidelity capabilities, there has been increasing exploration of the role of presence in VR studies (Dilanchian et al. 2021; Grassini et al. 2021; Kim et al. 2021; Kooijman et al. 2022; Magalhaes et al. 2021). Presence is a complex phenomenon integrating psychological, perceptual, and cognitive components that typically generate a sense of “being there” in the virtual scene (Heeter 1992; Slater 2018). Similarly, it has been argued that the perceived realism of the VR scene (e.g., stimulus fidelity, coherence) is another crucial element of presence that goes beyond purely *being there* (Weber et al. 2021). Several different factors have shown to increase the likelihood of a user’s experience of presence in a VR environment. For instance, multisensory integration of bodily signals (Grabarczyk and Pokropski 2016; Herbelin et al. 2016; Slater et al. 2009), the synchronicity of sensory stimuli (Kilteni et al. 2012), and the implementation of a virtual avatar (Grabarczyk and Pokropski 2016; Slater et al. 2009) in the VR environment have shown to be linked to presence. The latter factor will be the focus of the current study.

The inclusion of a user’s avatar (i.e., a representation of one’s body in the virtual environment) is considered to generally increase the sense of presence in VR (for overviews see Biocca 2014; Schultze 2010). Further, there is evidence to suggest that the sense of presence could be impacted by certain characteristics of an avatar (e.g., skin tone, gender-specific representations, level of realism). For instance, more realistic, human-like looking avatars do not necessarily increase presence but rather have the opposite effect, a phenomenon that has been thoroughly discussed in the literature and referred to as the *uncanny valley* issue of VR (Mori et al. 2012).

The role of an avatar on cybersickness has not yet been explored, but several studies have investigated how presence is related to cybersickness, revealing an inconclusive picture regarding the relationship between presence and cybersickness. A review of the literature by Weech et al. (2019) showed mixed evidence, with some studies finding a positive, a negative, or no relationship between the two phenomena at all. However, based on their evaluation of the existing studies, the authors conclude that cybersickness is negatively linked to presence, with increased levels of presence being accompanied by reduced cybersickness. A review of more recent studies revealed a similar, heterogenous pattern with regards to the relationship between presence and cybersickness. For instance, Maneuvrier et al. (2023) exposed their participants to a virtual shooting game and recorded their level of presence via the Presence Questionnaire (Witmer and Singer 1998) and cybersickness via the Simulator Sickness Questionnaire (SSQ) (Kennedy et al. 1993). The authors found significant, negative correlations between cybersickness and presence (see also Kim et al. 2020; Mostajeran et al. 2023; Pöhlmann et al. 2023). In contrast, Thorp and colleagues (2022) recorded presence and cybersickness during a virtual rollercoaster ride minute-by-minute and found positive correlations between the two variables (see also Breves and Stein 2023; Malone and Brünken 2021). No significant relationship between presence and cybersickness was also reported (Clifton and Palmisano 2020; Sepich et al. 2022; Teixeira and Palmisano 2021). Importantly, to the best of our knowledge, most studies investigating the relationship between presence and cybersickness used correlations to identify the relation between the two factors, which does not allow to address any causality. In other words, it remains unknown whether increased presence results in less cybersickness or whether increased cybersickness results in less presence. The present study will specifically focus on the former.

1.2 The present study

The primary goal of the present study was to establish a causal relation between presence and cybersickness. To achieve this, we actively manipulated the sense of presence by either including an avatar or not having an avatar in the virtual scene. Given the findings from previous research, we expected that the inclusion of an avatar would increase the level of presence in the virtual world and, consequently, reduce the severity of cybersickness. A secondary goal of the present study was to investigate how field dependence may affect cybersickness. Field dependence is a cognitive style that describes an individual's tendency to rely predominately on internal (e.g., bodily) or external (e.g., environmental) cues represented on a continuum ranging from highly field *dependent* (e.g., relying strongly on external cues such as visual information) to highly field *independent* (e.g., relying strongly on internal cues such as vestibular information). Field dependence (and, similarly, subjectively perceived verticality) have been linked to motion sickness (Cian et al. 2011; Mirabile et al. 2008; Witkin and Goodenough 1977) and cybersickness (Chung and Barnett-Cowan 2023; Maneuvrier et al. 2021) in the past, but these studies could not establish a robust link between the two. Thus, one of our study's goals was to further investigate this relationship.

2 Methods

2.1 Participants

A total of 54 younger adults participated in this study. Of those, three participants were removed from the data analysis due to increased simulator sickness severity *prior* to the start of the experiment (i.e., SSQ total score scores > 25), resulting in a final sample size of $N = 51$ (28 female and 23 male; age range = 19–38 years old, $M_{age} = 25.53$, $SD = 5.48$). Based on a priori calculations, this sample size allowed to detect moderate-to-large effects (Cohen's $d = 0.70$) with an acceptable power (1-beta = 0.80). All participants had no self-reported history or current diagnosis of stroke, vestibular disorders, musculoskeletal disorders, acute psychiatric disorders, or cognitive decline. All participants reported normal or corrected-to-normal vision. Visual acuity was assessed using a Snellen Test which all participants passed (i.e., scores better than 20/30). Participants were recruited from the community and received a $15 gift card as a token of appreciation. The study complied with the American Psychological Association Code of Ethics and was approved by the ethics review board of University Health Network and Toronto Metropolitan University.

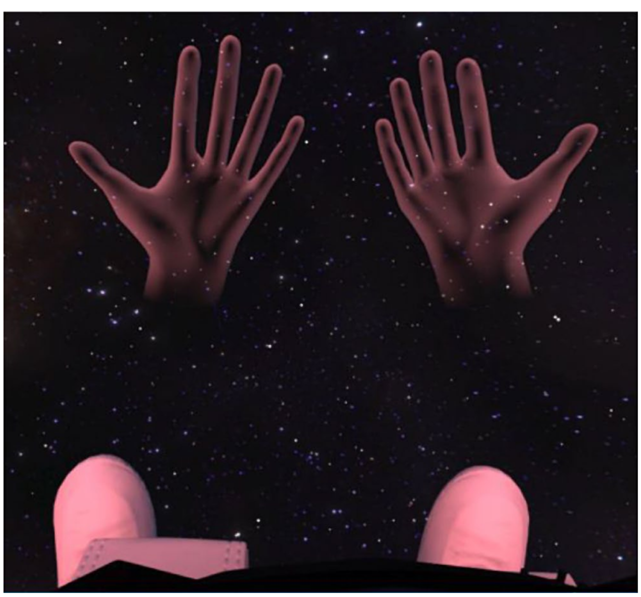

Fig. 1 Participant's view looking down at the avatar's feet and with their hands in front of their eyes

2.2 Design, stimuli, and apparatus

To manipulate the level of presence during the VR task, a self-avatar was shown to half of the participants, whereas no avatar was shown to the other half. Participants were randomly assigned to one of the two avatar conditions. Thus, our study was composed of a one-factorial design including the between-subjects factor *avatar manipulation* (avatar, no-avatar). In addition, we balanced the number of female and male participants to control for sex-related differences and their potential interaction with the avatar manipulation.

The stimulus consisted of an outer space environment which was presented to participants on a Hewlett Packard (HP) Reverb Omnicept G2 VR headset. This VR headset has a dual 2.89" LCD screen with a viewing resolution of 2160 × 2160 pixels per eye at a 90 Hz refresh rate. The horizontal field-of-view was approximately 114 degrees with Fresnel-Aspherical lenses and a hardware slider was used to adjust for differences in interpupillary distance (64 mm +/- 4 mm).

Participants were immersed in the outer space VR scene for a maximum duration of 15 min or until they reported moderate to high cybersickness (FMS score of 10 or higher, see *Dependent Measures* for details) which resulted in immediate termination of the stimulus. During VR exposure, participants were passively moved through the virtual scene following a pre-defined path including linear forward motion combined with additional rotations about the yaw, pitch, and roll axes (see Fig. 1). As the participants were moved through the virtual scene, objects resembling asteroids appeared and passed their viewpoint. Participants were asked to virtually "touch" these objects with their hands (i.e., to move their fingertips to the position of the asteroid) as quickly as possible, which resulted in the asteroids bursting into pieces. The main purpose of this task was to ensure that participants stayed engaged with the virtual scene. Background sounds of the asteroids passing the participant or bursting were added to the visual scene to increase the level of immersion.

In the avatar condition, participants were able to see an astronaut suit including a helmet, upper body, and legs/feet (Fig. 1). It is important to note that participants were only

Fig. 2 Manipulation of presence using avatar (left) and no-avatar (right) conditions

able to see the astronaut feet when they looked down in the VR environment. The edges of the helmet were also only visible during extensive head movements. However, for most of the actual task, participants were not able to see the astronaut feet or the helmet's edges in the avatar condition. Due to technical limitations, we were not able to simulate astronaut gloves but used "ghost hands" instead. Previous work did not suggest differences in presence ratings when comparing different avatar hands, including non-human (artificial, cartoon-like, robot) and human (male, female, androgynous) hands (Schwind et al. 2017). Instead, Knierim et al. (2018) reported that both artificial and realistic avatar hands significantly increased presence when compared to a condition with no hands present.

In the no-avatar condition, no representation of the participants' bodies and hands were shown (Fig. 2). In both conditions, we used the Leap Motion Controller for hand tracking which translated the participants' hands and finger movements accurately into the virtual scene.

2.3 Baseline measures

All participants completed the Computerized Rod and Frame (CRAF) as a measure of field dependence. During this task, participants sat in a dark room wearing glasses that limited their visual field to a screen in front of them. A squared frame with a vertical "rod" in the center of the frame was presented, and participants were asked to adjust the rod to be aligned with Earth's vertical (Bagust 2005). The surrounding frame was either tilted clockwise (18°), counter-clockwise (-18°), or stable. Errors in the alignment of the rod (measured in degrees) represented deviations from the true vertical. Larger alignment errors are considered to indicate a higher level of field dependence, as higher misalignments suggest that participants are more affected by the surrounding visual frame and rely less on internal cues (e.g., vestibular and proprioceptive information) for their perception of verticality.

In addition, participants also completed the Visually Induced Motion Sickness Susceptibility Questionnaire (VIMSSQ; Golding et al. 2021) to estimate individual susceptibility to cybersickness. The VIMSSQ was used to ensure that the two experimental groups (avatar, no-avatar) did not differ with regard to their cybersickness and motion sickness susceptibility. Independent t tests confirmed that the two groups did not differ[1], $t(49) = -1.76$, $p = .085$.

2.4 Dependent measures

2.4.1 Cybersickness

We measured cybersickness in two ways. First, the Simulator Sickness Questionnaire (SSQ; Kennedy et al. 1993) was assessed once prior and once immediately after VR exposure. The SSQ contains 16 items (e.g., discomfort, dizziness, stomach awareness, nausea) that have to be judged on a 4-point scale (*none*, *slight*, *moderate*, *severe*). Scores for the SSQ subscales nausea, oculomotor discomfort, and disorientation as well as a total-score were calculated using the weighting procedure suggested by Kennedy et al. (1993). The SSQ prior to the VR exposure was used to ensure that participants did not report elevated symptom severity prior to the experiment and that the two experimental groups did not differ with regard to their baseline cybersickness ratings.

[1] We also added the VIMSSQ as a covariate in additional statistical analysis to control for a potential impact of individual susceptibility on cybersickness ratings. Adding the VIMSSQ as a covariate did not change the results.

Second, cybersickness was measured during stimulus exposure minute-by-minute using the Fast Motion Sickness Scale (FMS; Keshavarz et al. 2011). The FMS is a rating scale ranging from 0 (*no sickness at all*) to 20 (*severe sickness*). Participants were asked to verbally indicate their level of cybersickness by reporting a single score every minute. Thus, the FMS allows to capture the time course of cybersickness with only minimal interruption. FMS scores were analyzed by calculating the peak score during both study conditions.

2.4.2 Presence

Presence was measured using the Presence Questionnaire (PQ; Witmer and Singer 1998), a 32-item questionnaire that can be separated into the four subscales of involvement, sensory fidelity, adaptation/immersion, and interface quality based on participant responses using a 7-point Likert scale (0 = *not at all to* 6 = *very much*). Higher scores in the interface quality subscale indicate worse quality, whereas higher scores on the other subscales indicate better adaptation/immersion, fidelity, and involvement. An example of a question from the involvement subscale was *"How natural did your interactions with the environment seem?"*, whereas an example from the sensory fidelity subscale was *"How well could you actively survey or search the virtual environment using touch?"*. An example of a question from the adaptation/immersion subscale was *"How proficient in moving and interacting with the virtual environment did you feel at the end of the experience?"*. Finally, the interface quality subscale included questions such as *"How much did the visual display quality interfere or distract you from performing assigned tasks or required activities?"* and was reversed scored such that higher scores indicated lower interface quality.

2.5 Presence manipulation check

To test the effectiveness of the chosen avatar manipulation (avatar vs. no-avatar), we introduced an additional task at the beginning of the study before participants were randomly assigned to one of the two experimental conditions. That is, all participants were exposed to both avatar manipulations (avatar and no-avatar) in counterbalanced order in the virtual outer space scene for one minute. For this task, the virtual scene remained static, and participants were encouraged to move their heads to explore the virtual scene and interact with their hands. In the avatar condition, participants were able to see the avatar's helmet and feet when looking down at their virtual body. After experiencing each condition, participants completed four questions adapted from Slater and Steed (1994) inquiring about their level of presence. These questions included:

1. "What would you rate your level of presence in the virtual world, with *1* being no presence at all and *100* being your level of presence in the real world?"
2. "Please rate your sense of being there in the computer-generated world on the following scale from *1* (not at all) to *7* (very much)."
3. "To what extent were there times during the experience when the computer-generated world became the reality for you, and you almost forgot about the real world outside? Please choose from *1* (at no time) to *7* (almost all the time)."
4. "When you think back about your experience, do you think of the computer-generated world as something that you saw, or more as something that you visited? Please choose from *1* (something that I saw) to *7* (somewhere that I visited)."

Participants also answered two questions that directly compared their experience with the avatar and no-avatar conditions. The two questions were: (1) *"Did the avatar change your level of presence in the virtual world?"* using a 7-point Likert scale ranging from 1 (*reduced significantly*) to 7 (*increased significantly*). (2) *"After looking at both virtual environments, which one of them made you feel a greater level of presence?"* with 3 response choices (*more presence with the avatar*, *more presence without the avatar*, *no difference between the two*). This manipulation check provided a direct comparison of presence ratings between the avatar and no-avatar conditions.

2.6 Procedure

Participants provided written consent prior to the study and were screened for their eligibility. After completing the baseline measures (CRAF, visual acuity, VIMSSQ) and the pre-study SSQ, the effectiveness of the avatar manipulation was tested. Participants then engaged in the main VR task. They were instructed to touch as many of the asteroids as they could while virtually traveling through the outer space scene. During VR exposure, participants verbally judged their severity of cybersickness using the FMS every minute. The VR stimulus stopped after 15 min or when participants reported moderate to high cybersickness (FMS score of 10 or higher), whichever came first. After the VR task, participants completed the post study SSQ and the PQ. Participants remained in the lab until cybersickness symptoms had subsided and participants felt prepared to leave the laboratory.

2.7 Data analysis

All data were analyzed using the statistical software R (Version 4.2.2; R Core Team, 2022). The significance level was a priori set to alpha = 0.05 for all analyses. Overall, no statistically relevant sex-related differences (main effects or interactions) were found for any of the dependent measures. Thus, we collapsed across both sexes and conducted independent samples *t* tests to compare the avatar and no-avatar conditions. The significance level was Benjamini-Hochberg corrected to adjust for multiple comparisons. This method was chosen given that it provides a balance between statistically significant findings and limits false positive occurrences.

3 Results

3.1 Presence manipulation

To ensure that the avatar manipulation (avatar vs. no-avatar) was successful, paired-samples *t* tests on the four presence questions were calculated to directly compare both experimental conditions. Results are presented in Table 1. Significant differences were found for all four questions, with higher ratings in the avatar compared to the no-avatar condition, confirming that manipulating presence via the avatar significantly impacted the level of perceived presence.[2] When asked to directly compare the avatar and no-avatar conditions, participants reported that the avatar increased their level of presence ($M = 5.16$, $SD = 1.50$). Finally, when asked to choose which of the two conditions induced more presence, 39 participants (76%) chose the avatar condition, 10 (20%) chose the no-avatar condition, and 2 participants (4%) indicated no difference between the two conditions.

3.2 The effect of presence manipulation on cybersickness

Of the 51 participants, 11 terminated the study prematurely due to severe cybersickness (i.e., FMS score > 10). Of those, three were in the avatar group and eight in the no-avatar group. However, for data analysis, participants who terminated the study prematurely were retained since peak FMS scores were analyzed.

The mean scores for each of the four SSQ subscales is shown in Fig. 3. Independent samples *t* test were calculated for all SSQ subscales to compare the effect of the avatar manipulation (avatar vs. no-avatar). Prior to stimulus presentation, no significant differences between the two avatar conditions were observed (p's > 0.93). After stimulus presentation, significant differences between the two avatar conditions were found for all SSQ subscales, including nausea, $t(49) = -1.21$, $p = .002$, $d = 0.96$, oculomotor discomfort, $t(49) = -2.58$, $p = .012$, $d = 0.72$, disorientation, $t(49) = -4.25$, $p < .001$, $d = 1.19$, and the total score, $t(50) = -3.81$, $p < .001$, $d = 1.07$, suggesting that the level of cybersickness was significantly higher in the no-avatar compared to the avatar condition.

The time course of the FMS ratings showing averaged minute-by-minute ratings as well as the mean peak FMS score are illustrated in Fig. 4. An independent samples *t* test revealed that the no-avatar group ($M = 6.12$, $SD = 3.15$) reported greater levels of motion sickness compared to the avatar group ($M = 2.65$, $SD = 2.90$), $t(49) = -4.09$, $p < .001$, $d = 1.15$.

3.3 Associations between presence, motion sickness, and field dependence measures

Figure 5 depicts the scores for each of the four PQ subscales separated by avatar manipulation (avatar, no-avatar). Independent samples *t* test were calculated to compare the results between the two avatar conditions. Results revealed

Table 1 Questions participants answered post experiencing avatar and no-avatar conditions

	Avatar manipulation M (SD)				
Presence Question	Avatar	No-Avatar	*t*(50)	*d*	*p*
What would you rate your level of presence in the virtual world (1-100)?	62.98 (23.92)	51.54 (26.02)	−4.12	0.46	0.001
How strong was your sense of being there in the computer-generated world (1–7)?	4.67 (1.48)	4.05 (1.76)	−3.47	0.38	0.001
To what extent were there times during the experience when the computer-generated world became the reality for you, and you almost forgot about the real world outside (1–7)?	3.21 (1.77)	2.45 (1.64)	−3.57	0.44	0.001
When you think back about your experience, do you think the computer-generated world as something that you saw or somewhere that you visited (1–7)?	3.61 (1.67)	3.10(1.98)	−2.18	0.28	0.034

Note d = Cohen's *d* effect size

[2] Because our assumptions for pairwise comparisons were not always met, we also performed non-parametric analyses; however, the results remained the same.

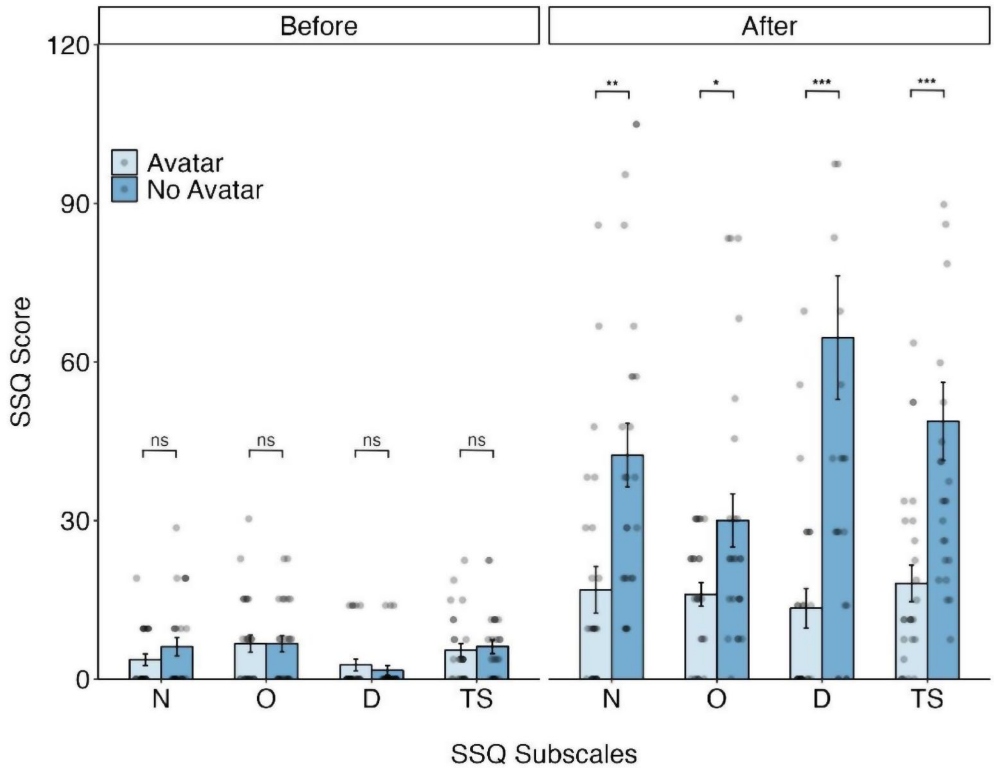

Fig. 3 SSQ subscale scores before (left) and after (right) stimulus presentation, separated by avatar manipulation (avatar, no-avatar). *Note*. Error bars represent standard error, dots represent individual data points. N = Nausea, O = Oculomotor discomfort, D = Disorientation, TS = Total Score. * $p < .05$, ** $p < .01$, *** $p < .001$

no significant differences in the adaptation/immersion, involvement, and sensory fidelity subscales between the two conditions (p's > 0.07). A significant difference was observed in the interface quality subscale, $t(49)$ = -3.02, $p = .016$, $d = 0.85$, suggesting that participants in the avatar condition ($M = 4.96$, $SD = 2.85$) scored lower than participants in the no-avatar condition ($M = 7.80$, $SD = 3.82$), implying better interface quality. As mentioned earlier in the Method section, this question is on a reverse scale with lower scores suggesting higher interface quality.

Correlations between presence, cybersickness, and field dependence are shown in Fig. 6. Significant, negative correlations of moderate to strong magnitude (r`s ranging from −0.27 to −0.46) were found between two PQ subscales (sensory fidelity and immersion) and all cybersickness measures (SSQ subscales, peak FMS), suggesting that higher scores on these presence scales were linked to lower cybersickness scores. The PQ subscale involvement showed only a significant negative correlation with the SSQ subscale of oculomotor discomfort but not with any other cybersickness measure. Significant positive correlations of moderate to strong magnitude (r`s ranging from 0.33 to 0.43) were found between the PQ subscale interface quality and all cybersickness measures, suggesting that participants who rated the interface quality as better (i.e., lower score) also reported less cybersickness. With regards to field dependence, no significant correlations were found with any cybersickness measures (r's ranging from -.04 to .27).

4 Discussion

The goal of the present study was to investigate how manipulating presence via an avatar may impact cybersickness in a VR environment. Presence was significantly stronger for the avatar than the no-avatar condition in the presence manipulation task, and the majority of participants preferred the avatar over the no-avatar condition. In accordance with our expectations, we found significant differences between the avatar and no-avatar group in all cybersickness measures. Additionally, we also found negative correlations of moderate to strong magnitude between cybersickness and presence measures, suggesting that more presence was associated with less cybersickness. Furthermore, no meaningful relationship between field dependence and cybersickness was found. We will discuss what these findings mean in detail in the following sections.

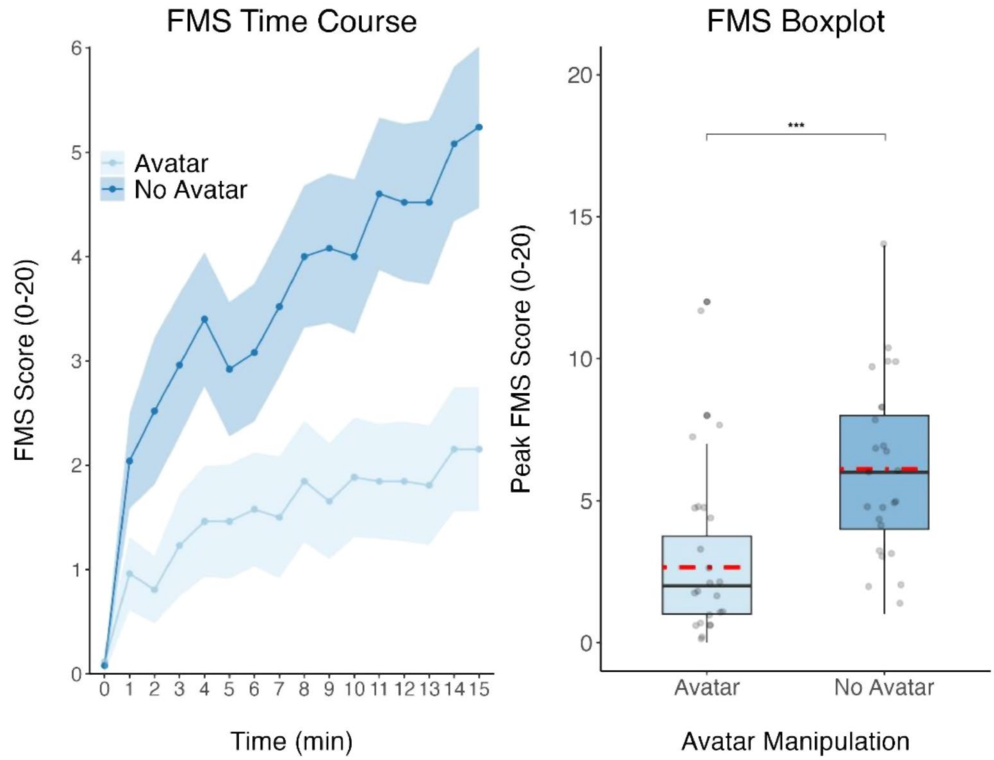

Fig. 4 Averaged FMS score minute-by-minute (left) and boxplot showing the peak FMS scores (right) separated by avatar condition (avatar, no-avatar). *Note*: The black solid line indicates the median and red dashed line represents the mean. Grey dots represent individual data points. In instances where participants terminated the study, the last FMS score that they reported before dropping out was used for the missing values in the time course. ***$p < .001$

4.1 The effect of an avatar on the level of presence

When participants were briefly exposed to both avatar and no-avatar conditions during the presence manipulation check at the beginning of the study, significant differences in presence were reported between the two conditions. This direct, within-subjects comparison of the avatar/no-avatar conditions confirmed that our manipulation of presence was successful. In contrast, there were no significant differences between the avatar and no-avatar conditions in three of the four PQ subscales measured after the VR task. The only reliable difference was reported for interface quality, with participants in the avatar condition showing significantly lower scores (suggesting better interface quality) compared to the no-avatar condition. This discrepancy in presence ratings between the presence manipulation check and the post-stimulus PQ is somewhat surprising. However, we believe that the ratings from the manipulation check are more reliable than the PQ for a couple of reasons. First, participants were able to experience both conditions and make direct comparisons between the avatar and no-avatar conditions, eliminating inter-individual differences that may have occurred when comparing presence ratings between two different participant groups. When directly comparing the two conditions, the majority of participants preferred the avatar as compared to the no-avatar condition with regard to presence. Participants also indicated that the avatar increased their level of presence, although this increase in presence was rather slight. Second, it is possible that the PQ is not an optimal measure of presence, but rather blends elements of immersion and factors leading to presence, an issue raised and described in detail by Slater (1999), who argues that the questionnaire makes it difficult to separate cognitive processes of an individual and the characteristics of the system. This is particularly important given that individual characteristics such as traits and personal experiences can influence how one perceives presence in VR environments (Riva et al. 2003). Others have also argued that the phrasing of the PQ might be interpreted as broadly technology related and some rephrasing might help with the ambiguity (Lessiter et al. 2001). Thus, the questions used after the manipulation check – which were adapted from (Slater and Steed 1994) – seem, in retrospect, more appropriate to capture presence in our study. Third, it is possible that the degree of presence would have changed overtime. Even though participants may have experienced higher levels of presence in the avatar versus no-avatar condition in the initial moments of the study such as during the manipulation check or the first few

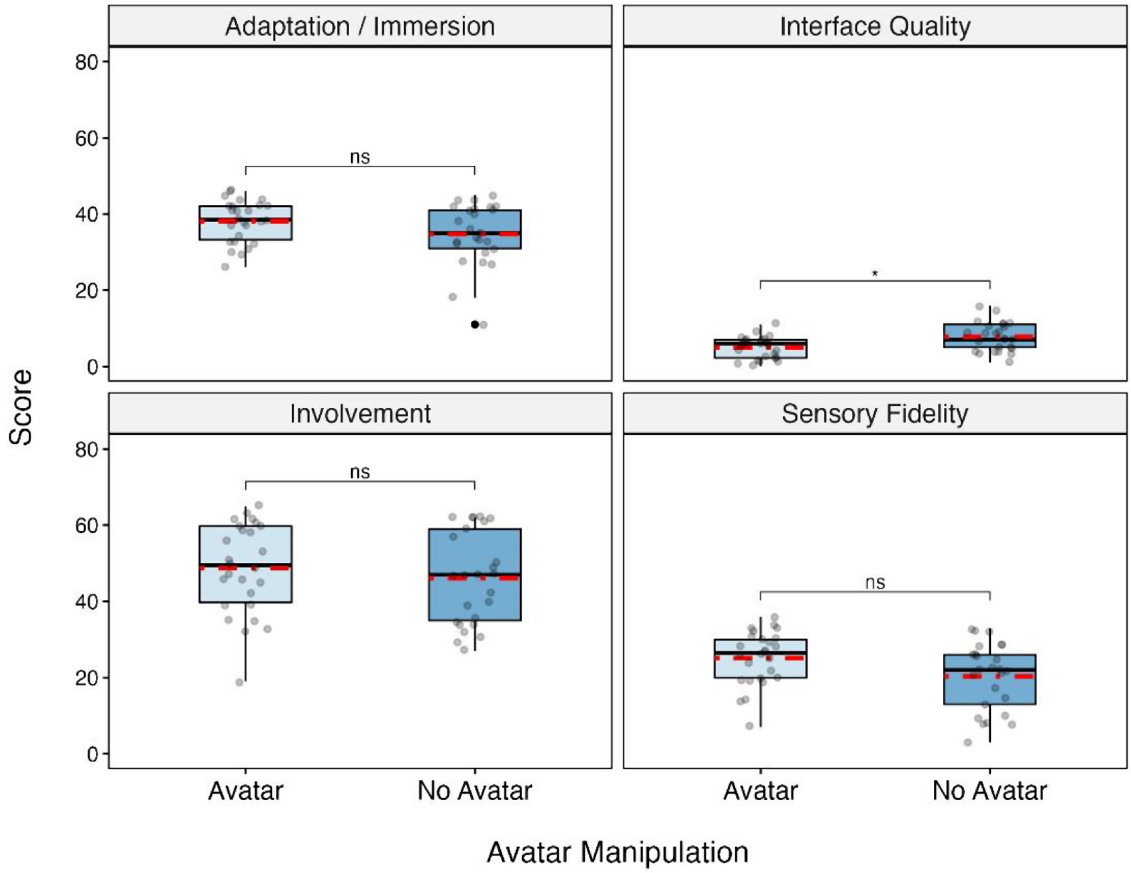

Fig. 5 Boxplots for all four subscales of the PQ as a function of avatar manipulation. *Note*: The black solid line within each box indicates median and red dashed line represents the mean. $*p < .05$

minutes of VR exposure, the degree of presence may have levelled out over time. Taken together, we therefore argue that our manipulation of presence was indeed successful.

4.2 The relationship between presence and cybersickness

The relationship between cybersickness and presence has long been in contention and has given rise to conflicting results. From a theoretical point of view, considering the sensory conflict theory of motion sickness (Reason 1978; Reason and Brand 1975), both a negative as well as a positive relationship between presence and cybersickness seem plausible. On the one hand, it could be argued that an increased sense of presence also increases a sensory conflict, as the visual system convincingly suggests self-motion through the virtual world (vection), which contrasts the information from the vestibular and proprioceptive senses. However, more vection does not necessarily correspond to more cybersickness (see Keshavarz et al. 2015), weakening this line of argument. On the other hand, it could be argued that an increased sense of presence can help to overcome or solve the apparent sensory conflict. In other words, if the virtual world fully replaces the real world, the visual cues might overrule the vestibular and proprioceptive cues, allowing to more easily solve the visual-vestibular conflict.

Over the past years, there seems to be some consensus suggesting that increased presence is associated with lower levels of cybersickness (Weech et al. 2019). However, empirical evidence for this assumption is inconclusive as demonstrated by the fact that several recent studies found a negative (Maneuvrier et al. 2023; Mostajeran et al. 2023; Pöhlmann et al. 2023), a positive (Breves and Stein 2023; Malone and Brünken 2021; Thorp et al. 2022), or no relationship (Sepich et al. 2022) between cybersickness and presence. Most importantly, to the best of our knowledge, all previous work on cybersickness and presence used a correlative approach, while the current study was the first to actively manipulate presence in order to alter the severity of cybersickness.

Taken together, the findings from the present study are in support of the assumption that presence and cybersickness may be negatively associated. This is evidenced by the fact that we found negative correlations between

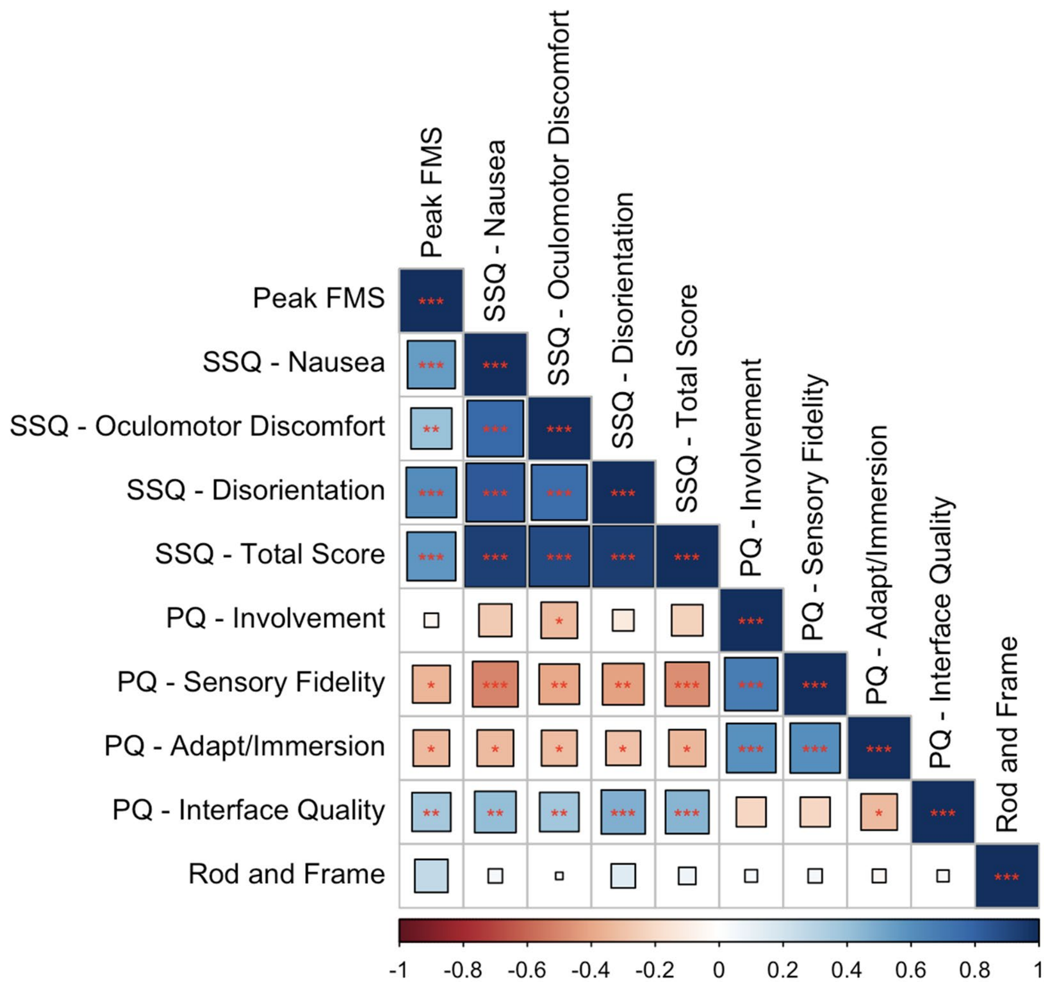

Fig. 6 Pearson correlations between cybersickness (FMS, SSQ), presence (PQ), and field dependence (Rod and Frame) measures. *Note*: $*p < .05$, $**p < .01$, $***p < .001$

cybersickness and most elements of the PQ (considering the shortcomings of the PQ as stated previously), demonstrating that increased presence is linked to reduced cybersickness. Additionally, our presence manipulation did also significantly impact cybersickness: participants in the avatar group (high presence) reported significantly less cybersickness as measured by the SSQ and the FMS compared to the no-avatar group (low presence). However, it is important to note that the reduction in cybersickness in the avatar condition might have been caused by factors other than presence. For instance, having an avatar available may also change the level of embodiment, which refers to the sensation of *being in control of one's body* within a VR environment (Riva et al. 2003). It is possible that participants in the avatar condition may have experienced greater levels of embodiment because their finger and hand movements were accurately transferred to and illustrated in the VR scene. Since embodiment is positively correlated with presence (Suk and Laine 2023), a greater sense of embodiment may have contributed to reduced cybersickness in addition to or in lieu of presence. Additionally, an astronaut helmet was part of the avatar presented in one of the two conditions. Although this helmet was only visible during more pronounced head tilts at the periphery of the visual scene, we cannot fully rule out that the helmet may have acted as a reference frame, which has been discussed to reduce cybersickness (Cao et al. 2018; Luks and Liarokapis 2019; Prothero 1998; Shi et al. 2021; Tian et al. 2022).

4.3 The relationship between field dependence and cybersickness

The role of field dependence on cybersickness and presence is not well understood. There is some evidence that more field dependent individuals may be at an elevated risk of experiencing cybersickness (Maneuvrier et al. 2021), although the evidence for this relationship remains sparse. Based on theoretical considerations, a positive relationship between field dependence and cybersickness seems plausible, as a stronger dependence on visual cues may increase a potential visual-vestibular conflict (i.e., visual cues indicating self-motion, vestibular cues indicating stasis), which may lead to increased cybersickness. However, the present study did not reveal any significant relationship between field dependence and cybersickness, as only weak-to-moderate correlations were observed, suggesting that participants who were less field dependent reported lower SSQ scores. To better understand the relationship between these two phenomena, more systematic research using well-established measures of cybersickness and field dependence are highly desirable.

4.4 Limitations and future outlook

As mentioned above, one of the limitations was the use of the PQ, which may have not been an optimal choice to capture presence in the current study (Slater 1999). Given the shortcomings of the PQ, in hindsight, it would have been more appropriate to use the same four questions after stimulus presentation that were used during the presence manipulation task. Another limitation is that the avatar in our study was not fully animated; that is, the legs in the avatar condition were not synchronized with the movement of the VR user due to technological limitations which may have contributed to a lower sense of presence overall. Previous research has shown that visibility and synchronization of body parts may influence presence experienced by the user (Freiwald et al. 2021; Heidicker et al. 2017; Waltemate et al. 2018; Yoon et al. 2019); including leg tracking in future studies would be interesting to fully explore the impact. Similarly, we were not able to replicate astronaut gloves and arms due to technical limitations and used "ghost hands" instead. However, previous work (Bartl et al. 2022) suggested that having parts of an avatar available (e.g., hands only) is as effective as having a full-body avatar for inducing presence and that presence ratings for various avatar hands, including non-human (artificial, cartoon-like, robot) and human (male, female, androgynous) hands, can be considered similar (Schwind et al. 2017). Lastly, we used an outer space environment as our stimuli which may have resulted in lower presence rating overall, given that none of our participants have experienced being in space in real life. Using a more ecologically valid and realistic environment might strengthen the sense of presence in future studies.

Future studies may also consider implementing additional experimental conditions to better understand whether active presence manipulations could reduce cybersickness. For instance, it would be interesting to explore whether presence can be manipulated more gradually across multiple conditions (e.g., very low, low, medium, high, very high) and how this would impact cybersickness. In this regard, simultaneously recording presence and cybersickness ratings during VR exposure would help to better understand how these two phenomena develop over time during a VR session. Furthermore, to fully capture the relationship between presence and cybersickness, it would also be intriguing to manipulate the level of cybersickness while recording changes in presence. However, this manipulation is more complicated, as most experimental manipulations affecting cybersickness may directly affect presence as well (e.g., field of view, optical flow, stimulus speed). To test the impact of cybersickness on presence, it would be possible to induce different levels of cybersickness or motion sickness *prior* to VR exposure, for instance through off-vertical axis rotations (Golding et al. 2009). Lastly, adding physiological measures such as heart rate, heart rate variability, facial skin temperature, electrodermal activity, or eye movements to well-established self-reports (e.g., SSQ, FMS) may support the development of objective markers for cybersickness and presence in the future (Islam et al. 2022; Keshavarz et al. 2022; Pöhlmann et al. 2024; Wang et al. 2023). The technological advancements of modern VR systems allow to better integrate these physiological measures and explore associations with cybersickness and presence.

5 Conclusion

The current study investigated the relationship between presence and cybersickness in a VR environment by manipulating the level of presence using an avatar. Our results demonstrated that providing an avatar in VR can significantly reduce cybersickness and that presence is negatively correlated with cybersickness. In addition, we found no meaningful correlation between field dependence and cybersickness, as well as no sex-related differences. Based on our findings, the inclusion of an avatar in VR environments reduces cybersickness. However, further research is required to understand the extent to which this is related to an increased sense of presence. Nevertheless, it seems desirable to include an avatar, when possible, to reduce cybersickness.

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Data availability No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate This study was conducted in accordance with the principles specified in the Declaration of Helsinki and was approved by the research ethics boards of the University Health Network and Toronto Metropolitan University (2022 – 123). Written consent was obtained prior to the beginning of the experiment.

Competing interests The authors declare no competing interests.

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