Virtual Reality
https://doi.org/10.1007/s10055-023-00805-z

ORIGINAL ARTICLE

Demographic differences in presence across seven studies

Alison Jane Martingano[1,2] · Ja-Nae Duane[3] · Ellenor Brown[4] · Susan Persky[1]

Received: 6 September 2022 / Accepted: 4 May 2023

Abstract
It is often necessary for virtual reality (VR) users to experience a sense of presence for the benefits of VR applications to be realized. However, feelings of presence are subjective and depend not only on the nature of the VR environment but also on the users' unique characteristics. To maximize the likelihood of achieving desired VR outcomes, it is important to understand the user characteristics that impact the likelihood of users' feelings of social and environmental presence. Addressing this knowledge gap is an important first step toward verifying whether all user populations have access to equally efficacious VR experiences. To this end, we report data from seven independent samples collected within one laboratory group (total $N = 1145$). In these studies, participants were asked to perform tasks in VR such as traversing environments, pointing at and selecting objects, and interacting with virtual humans. Meta-analyses revealed that, on average, feelings of presence were not significantly related to age or gender, but differed by racial group membership. Significant racial differences in presence were found for both environmental and social presence. Black participants reported approximately half a standard deviation more presence than White participants. No overall differences between Asian and White participants' reported presence were found. These findings provide a context for future studies that may explore demographic differences in presence directly.

Keywords Presence · Virtual reality · Age differences · Gender differences · Racial differences

1 Introduction

VR technologies are employed in a wide variety of fields including medicine (Chirico et al. 2016), education (Freina and Ott 2015), manufacturing (Mujber et al. 2004), engineering (Coburn et al. 2017), and military training (Bowman and McMahan 2007). Often, a sense of presence, or 'being there' in the virtual environment is central to realizing the maximum benefit of these applications. For example, VR has been used successfully as exposure therapy for specific phobias (e.g., Arachnophobia, Acrophobia) (Carvalho et al. 2010). However, for the exposure to be effective, virtual environments must activate similar fear responses in users as an analogous physical environment, which can only occur if the user feels as if they are existing in the fear-inducing situation (Hodges et al. 1995). Feelings of presence are essential to the success of many VR outcomes, including task performance (Slater et al. 1996), training efficacy (Wallis and Tichon 2013), persuasiveness (Kim and Biocca 1997), analgesic distraction (Triberti et al. 2014), and empathy (Barreda-Ángeles et al. 2020).

To date, most research in this area has focused on the technological affordances of VR hardware and software that can heighten or dampen users' feelings of presence. For example, more fully enveloping and more interactive environments are associated with a heightened feeling of presence in users (see Cummings and Bailenson 2016 for review). However, because presence is subjective, individual users' perceptions of presence can vary dramatically in similar or even identical virtual environments (Ling et al. 2013; Wallach et al. 2010). The immersive characteristics of the VR system and the user's unique characteristics and tendencies, together, dictate perceptions of presence. Therefore, to

✉ Susan Persky
perskys@mail.nih.gov

1 Social and Behavioral Research Branch, National Human Genome Research Institute, National Institutes of Health, Bethesda, MD, USA

2 Present Address: Department of Psychology, University of Wisconsin – Green Bay, Green Bay, WI 54311, USA

3 Department of Information and Process Management, Bentley University, Waltham, MA, USA

4 Office of Science and Engineering Laboratories, Center of Devices and Radiological Health, US Food and Drug Administration, Silver Spring, MD, USA

Published online: 17 May 2023

maximize the likelihood of achieving desired VR outcomes, we must understand whether and how user characteristics impact presence experiences.

In anticipation of evaluating VR application efficacy across user demographics, it is important to understand underlying differences between groups related to these outcomes. Past studies have explored the relationship between presence and demographics, but largely as covariates (Oh et al. 2018). There is a need to specifically focus on the potential influence of demographic variables on their own. To help address this gap, we report data on these relationships from seven independent samples. Within these studies, participants were asked to perform varying tasks (e.g., traversing environments, pointing at and selecting objects, interacting with virtual humans). We then report meta-analyses examining demographic differences in environmental and social presence across these virtual experiences. The results of these analyses can assist in promoting VR design approaches that engender presence even in groups where presence may be more difficult to elicit. As such, understanding potential group differences in presence is critical to ensuring that this emerging technology is accessible to and effective for all in future.

1.1 Presence within virtual environments

Presence is characterized as an individual's subjective experience of reality. It has long been established that the psychological experience of being within the virtual environment or having "presence" is essential for a good experience within virtual reality (Slater and Wilbur 1997). Although researchers have not aligned on a specific definition of presence (see Felton and Jackson 2021; Schubert 2009; Schuemie et al. 2001), at the core of this concept is a feeling of being situated within the virtual environment. In other words, the user begins to accept the virtual environment as a real one (Scavarelli et al. 2020). Although researchers have identified and categorized several types of presence (Lombard and Jones 2015), this paper focuses on two: environmental and social presence.

Environmental presence, sometimes referred to as spatial presence, refers to the sense of being physically located within a digital environment (Lombard and Jones 2015). This dimension of presence is measured by how real the virtual space and its objects seem to the user (Bailey et al. 2012). Such presence occurs when the virtual world is responsive to user input in naturalistic ways (e.g., active physical responses) (Lee 2004) and the VR environment provides "the illusion that the scenario being depicted is actually occurring" (Slater 2009, p. 3540). The immersiveness of the virtual environment creates a level of realism (Baus and Bouchard 2014) in which the user's expectations are met and the environment is considered authentic (Baños et al. 2005). Environmental presence is particularly important in order for users to be able to generalize experiences they have in VR to real-world environments (Bailey et al. 2012; Duane et al. 2022).

Social presence refers to the concept that VR users feel that they coexist in the same environment (Heeter 1992; IJsselsteijn et al. 2000; Lee 2004) and experience others (e.g., virtual humans, avatars of humans) as social entities (Biocca 2006; Biocca et al. 2003). Through the lens of social presence, there is a sense of being together with another social entity and responding to social cues within the interaction (Biocca et al. 2003). Additionally, the perceived social connection can influence interactions between individuals who are physically separated (Blascovich 2002; Short et al. 1976; Garau et al. 2005; Parsons et al. 2017; Oh et al. 2018). For example, social presence can positively influence learning interactions between individuals within virtual classrooms (Wei et al. 2012) as well as positively influence learning and inquiry for students (Garrison et al. 2010).

2 Demographic differences in presence

In recent years, researchers have begun to consider how the demographics of VR users may influence their experiences within VR environments, particularly during interactions with members of other social groups (e.g., Taylor et al. 2020). It is no surprise that cultural norms will influence the design of VR experiences. However, a particular concern is that if we make assumptions about the target audience of a VR experience, it could result in VR experiences that are more relatable and comfortable for certain demographic groups, possibly at the expense of others. Users who fall outside of the 'expected' age, gender, or racial group may not see their lived experiences reflected as accurately within VR, and potentially this may lead these users to feel less presence. Moreover, a lack of diversity within user design and testing may exacerbate this issue, leading to potential inequalities in the efficacy of VR experiences. It is therefore critical to examine potential demographic differences in presence and to determine if these differences are more likely to occur for certain types of presence (i.e., environmental vs social). To date, existing research on demographic differences in presence is somewhat limited for age and gender, and almost nonexistent for race.

2.1 Age

There is existing evidence of age differences in presence, but this evidence appears stronger for environmental presence than social presence. Generally, older users appear to experience less environmental presence than younger users (Cho et al. 2015; van Schaik et al. 2004; Ausburn and

Ausburn 2008). However, this research has generally compared middle-aged adults (e.g., 30–60) to young adults (e.g., 20–30). More recent research that has recruited older adults (e.g., 60+) and compared them to younger adults has found either no age-related differences in environmental presence (Corriveau Lecavalier et al. 2020; Felnhofer et al. 2012; Mitzner et al. 2021) or the reverse trend, with older adults reporting greater environmental presence than younger adults (Dilanchian et al. 2021). These mixed results could potentially indicate a U-shaped relationship between environmental presence and age, dropping in middle age. However, as older adults have only been studied more recently, it is difficult to disentangle the effects of age from those of time. Potentially the relationship between age and environmental presence may be changing over time, with more modern hardware and software yielding different results from earlier technology. To date, the nature of the relationship between age and environmental presence, if any exists, remains unclear, and a more thorough examination of these trends, as well as potential moderators, would be beneficial.

In regards to social presence, some studies suggest that age is associated with lower levels of presence (Cho et al. 2015; Siriarava and Ang 2012), although many more studies have found no correlation between social presence and age (Hite et al. 2019; Felnhofer et al. 2012; Hauber et al. 2005; Lim and Richardson 2016; Kim et al. 2004; Richardson and Swan 2003). These mixed results suggest that it is worth exploring how age relates to presence, and how this may differ by the nature of VR experience in question.

2.2 Gender

VR researchers have previously claimed that gender may be an important demographic factor moderating the experience of environmental and social presence (IJsselsteijn 2004; Lombard and Ditton 1997). However, the literature on gender and presence is mixed in its findings. For environmental presence, several studies have found no evidence of gender differences (De Leo et al. 2014; Khashe et al. 2018; Melo et al. 2021; Pallavicini et al. 2019; Weech et al. 2020), other studies have found that women report higher levels of environmental presence in a variety of VR settings including simulation of a medical emergency (Paquay et al. 2022), a VR tourism experience (Melo et al. 2022), and various entertainment VR experiences (Grassini et al. 2021; Gonçalves 2018). Still, other research has found that men report higher levels of certain types of environmental presence (Felnhofer et al. 2012, 2014; Lachlan and Krcmar 2011). For example, men reported higher levels of two environmental presence components (performance and ability to act in the VR environment) in a VR assembly line environment, with no gender differences on other components of presence (Sagnier et al. 2019). Similarly, men in other studies have reported a greater ability to act and perform in a VR classroom (Gamito et al. 2008) and higher levels of behavioral control and ease of use in a driving task (Chang et al. 2020). These results may suggest that women report less presence if presence requires actual and/or perceived competence. Relatedly, men's sense of environmental presence tends to be higher than women's in interactive VR experiences that require the manipulation of objects, but this trend appears to be reversed for less interactive experiences (Slater et al. 1998a, b). Recent research has also suggested that gender differences in presence may emerge in interaction with VR design choices. For example, women's presence appears to be more heavily impacted than men's when asked to embody a VR avatar with opposite gender hands (Schwind et al. 2017). Moreover, the type of locomotion control used in VR (e.g., teleporting vs. steering) might impact women's sense of presence to a greater degree than men, who tend to feel a similar sense of environmental presence regardless of locomotion type (Clifton and Palmisano 2020).

In regard to social presence, the results are also mixed, with several studies finding that gender has no impact on social presence (Cho et al. 2015; Felnhofer et al. 2014; Kim 2004; Schifter et al. 2012). However, several other studies find that women report more social presence than men (Giannopoulos et al. 2008; Johnson 2011; Bailenson et al. 2005). Additionally, there is evidence that women respond more emotionally to virtual avatars than men (Mousas et al. 2018) and are more likely to feel a sense of embodiment with virtual avatars (Scheibler and Rodrigues 2018). Still, rigorous investigation of gender differences in social presence is lacking in the literature (Lin et al. 2011).

2.3 Race

When interracial contact occurs in VR, different racial groups are likely to bring contrasting interpersonal concerns (Taylor et al. 2020). As highlighted by Taylor et al., these concerns can include concerns about being stereotyped, experiencing bias, and/or appearing prejudiced, and, just as in live interracial interactions, non-White VR users can experience implicit and explicit racial prejudice in VR, particularly to the extent that their racial identity is visible. Virtual worlds are often White-dominated (Lee and Park 2011), and so non-White users are less likely to feel represented within them. Moreover, non-White users may even feel pressure to change their avatar to appear as White so to blend into the racial norm and avoid harassment (Blackwell 2019). One Back VR user interviewed by Blackwell reported "Since I'm going to be playing with a bunch of Americans anyway—and I can choose to get treated like a black person or not get treated like a black person—I'm probably going to choose not to get treated like a black person." (Blackwell 2019, pp. 13). To date, it is unclear whether and how these experiences might impact the level of presence felt by different racial groups while in VR.

Empirical evidence on whether racial groups experience different levels of presence is scarce. The lack of information on this topic likely reflects the limited diversity of participants included in the research (Parsons and Rizzo 2008). For example, in research investigating the presence associated with embodying male or female hands, all hands were rendered with a White skin tone and only White participants were included (Schwind et al. 2017). Moreover, when participants of other races are included in research, they are often in such small numbers that statistical comparisons are inconclusive. For example, Beverly et al. (2021) had less than five participants in each racial category other than White. This study is notable because the authors did explore potential racial differences in their dataset, but given that these analyses were underpowered, it is perhaps unsurprising that they found no significant racial differences in environmental presence. Similarly, in a small sample of Black and White hemodialysis patients, no statistically significant racial differences were found in presence during a VR mindfulness intervention (Hernandez et al. 2021). In a more well-powered study, other researchers found no reported differences in environmental presence between ethnic groups in Israel (Arab vs Jewish; Almog et al. 2009). To our knowledge, there is no existing research examining racial differences in social presence. Generally, our survey of the literature suggests that the lack of reporting of racial differences is likely due to a lack of data, rather than indicating an inherent lack of group differences.

3 Method

The current analysis included data from seven experimental trials conducted for other purposes (see Table 1) between 2009 and 2020 through the Immersive Simulation Program at the National Human Genome Research Institute, National Institutes of Health. All samples were independently recruited. All research participants were recruited from the local community. VR use occurred within the program's lab facility within the Clinical Center at the National Institutes of Health main Bethesda MD campus. Participants in all studies provided informed consent to participate were compensated for their participation, and all studies were approved by the relevant institutional review board.

Each study employed one of two types of VR settings: a buffet restaurant environment called the VR Buffet (Persky et al. 2018) or a clinical exam room environment. Both VR programs were created using the Vizard virtual reality platform. These studies were selected because they administered self-report measures of environmental presence and/or social presence and recorded participants' self-reported age, gender, and race.

3.1 VR environments

3.1.1 The VR buffet

The VR Buffet is a simulated buffet restaurant in which parental food choices for their child are assessed by tracking parents' virtual food selections (Fig. 1; Persky et al. 2018). Participants' physical movements drive the viewpoint in the virtual world such that walking around the physical room corresponds to walking around the virtual buffet. Participants make food selections at the virtual

Table 1 Characteristics of the VR environment for each research study

	Year	Content	Locomotion	Headset	Type of presence	Description of study
Study 1	2009	Virtual clinic	Walking	Nvisor SX60	Environmental and Social	Assess medical student reaction to a White, female virtual patient's weight in a clinical scenario
Study 2	2011	VR Buffet	Walking	Nvisor SX60	Environmental	Measure influence of child risk information provision on mothers' feeding behavior
Study 3	2012	Virtual clinic	None	Nvisor SX60	Social	Assess reaction of women with overweight to a White, male virtual provider's messages
Study 4	2014	Virtual clinic	None	Nvisor SX60	Social	Assess reaction of women with overweight to a White, male virtual provider's messages
Study 5	2017	VR Buffet	Walking	HTC Vive	Environmental	Measure influence of messages about child diet on parent feeding behavior
Study 6	2019	VR Buffet	Walking	HTC Vive	Environmental	Measure influence of child risk information provision on parents' feeding behavior
Study 7	2020	Virtual clinic	None	HTC Vive Pro	Social	Assess medical student use of virtual patient's genomic risk information in the clinical scenario. Virtual patients were randomized to appear Black or White

Fig. 1 Screenshots of buffet and clinical VR environments

buffet using a controller and select a virtual cash register to indicate completion.

3.1.2 VR clinical simulations

Several VR clinical simulations are included in which participants are immersed in a virtual medical exam room as either the healthcare provider or patient and asked to interact verbally with a virtual human playing the opposite role. When physician-trainees (as opposed to patients) are the users, they are also asked to read the virtual patient's medical records on a virtual computer monitor or tablet situated within the VR environment. A research assistant controls the pre-recorded statements of the virtual human interaction partner. In most cases, users are seated in this virtual environment, although there is also a version in which users can walk around and approach their virtual interaction partner (Fig. 1).

3.2 VR equipment

All studies were conducted within the same physical lab environment which consisted of a room fitted with a six degrees of freedom (6-DOF) VR headset system. The headset and equipment in use differed across studies (see Table 1). The earlier VR system included an nVisor SX60 headset with a WorldViz Precision Point Tracking System. A hand-held presentation pointer was modified to provide hand control of the selection tool in the VR Buffet environment. Later systems included an HTC Vive headset with an integrated tracking system or an HTC Vive Pro headset with its integrated tracking system. In both cases, the relevant Vive/Vive Pro controllers were used for hand control when needed.

3.3 Measures

3.3.1 Environmental presence

For study 1 participants responded to 19 items from the Presence Questionnaire (Witmer and Singer 1998) on a 7-point scale. Participants' responses to questions 14, 17, and 18 were reverse coded and items were averaged to give a mean environmental presence score out of 7. For studies 2, 5, and 6 participants responded to five questions measuring environmental presence: (1) "To what extent did you feel involved in the virtual world?," (2) "To what extent did you feel like you were inside the virtual world?," (3) "To what extent did you feel surrounded by the virtual world?," (4) "To what extent did it feel like you visited another place?," and, (5) "How much did the virtual world seem like the real world?" (Fox et al. 2009). Individual studies used slight variations in phrasing (see Appendix A for exact phrasing). Participants responded on a 5-point scale (1 = Not at all, 2 = Slightly, 3 = Moderately, 4 = Very Much, 5 = Extremely). Responses were averaged to give a mean environmental presence score out of 5.

3.3.2 Social presence

For studies 1, 3, 4, and 7 participants responded to three questions adapted from Bailenson et al. (2005) measuring social presence. The phrasing of these questions differed depending on whether the participant was taking on the role of a patient or a physician: (1) "Even when my [doctor/patient] was present, I still felt alone in the virtual room.," (2) "I felt like there was someone else in the clinic room with me.," and, (3) "I felt like my [doctor/patient] was aware of my presence in the room." Individual studies used slight variations in phrasing (see Appendix A for exact phrasing). Participants for studies 1, 3, and 4 responded on a 7-point

Table 2 Participant demographics

Study	Age (years)		Gender (*N*, %)		Race (*N*, %)			
	Mean (SD)	Range	Women	Men	White	Black	Asian	Other
1	26.36 (2.46)	20–40	100 (50%)	100 (50%)	111 (55%)	32 (16%)	43 (22%)	14 (7%)
2	37.50 (5.62)	21–49	221 (100%)	0 (0%)	114 (52%)	81 (37%)	5 (2%)	21 (10%)
3	34.77 (8.82)	20–50	200 (100%)	0 (0%)	59 (30%)	109 (55%)	9 (4%)	23 (11%)
4	35.2 (9.25)	20–50	201 (100%)	0 (0%)	89 (45%)	87 (44%)	9 (4%)	13 (7%)
5	37.70 (5.75)	23–56	124 (66%)	64 (34%)	87 (47%)	47 (25%)	27 (14%)	26 (14%)
6	39.46 (6.40)	24–71	98 (52%)	92 (48%)	125 (66%)	33 (17%)	19 (10%)	13 (7%)
7	26.28 (2.21)	23–38	51 (63%)	30 (37%)	34 (43%)	16 (20%)	25 (31%)	5 (6%)

Some participants chose not to report their age, gender and/or race. *N* for each demographic comparison is therefore provided in the tables below

Table 3 Correlation with age

	N	*r*	*p*
Environmental presence			
Study 1	200	−.08	.252
Study 2	218	−.16	.021
Study 5	188	−.004	.962
Study 6	190	.04	.546
Social presence			
Study 1	200	−.08	.243
Study 3	199	−.03	.663
Study 4	201	.05	.459
Study 7	81	−.21	.055

Table 4 Results from ANOVA by gender

	Mean (standard deviation)		ANOVA		
	Women	Men	*N*	*F*	*p*
Environmental presence					
Study 1	4.11 (0.68)	4.33 (0.60)	200	5.79	.017
Study 5	3.83 (0.80)	3.57 (0.87)	188	4.19	.042
Study 6	4.16 (0.60)	3.85 (0.77)	190	9.99	.002
Social presence					
Study 1	4.67 (1.22)	4.75 (1.13)	200	0.23	.631
Study 7	2.51 (0.86)	2.17 (1.12)	81	2.41	.125

from 1 = strongly disagree to 7 = strongly agree, while participants for study 7 responded on a binary scale Agree/Disagree. Participants' responses to question 1 were always reverse coded and scores were averaged to give a mean social presence score.

3.4 Demographic variables

Participants self-reported their age, gender, and race (see Table 2). In order for a racial group to be considered for analysis within a given study at least 10 participants in the study needed to identify with that race.

4 Results

We first examined zero-order correlations between presence and age for each study (see Table 3). Second, when studies contained participants of multiple genders, we conducted one-way ANOVAs examining the relationship between participant gender and presence (see Table 4). Third, we conducted one-way ANOVAs examining the relationship between participant race and presence. When there were three racial groups, we examined planned contrasts to assess differences between individual racial groups (see Table 5). R code and data for analyses for studies 1–7 are publicly available via OSF (https://osf.io/pd3bk/?view_only=f305aaade1584a2a8413bee8cfa05ce2).

In all analyses, we retained all original scale items and response options (without transformation) since these may influence participant responses (Rivers et al. 2009). For this reason, we caution readers that it is not possible to compare raw presence scores between included studies. We provide meta-analyses for this purpose.

We conducted random effects meta-analyses (DerSimonian and Laird 1986) using Comprehensive Meta-Analysis V3 (CMAv3) software (Borenstein et al. 2006) to determine the overall differences in presence based on demographic variables. Meta-analysis can combine studies that use different measures by transforming the effect sizes from each study into a common metric. This common metric is then used to calculate a summary estimate of the effect size across all studies. This allows for the comparison of effect sizes across studies that use different measures including continuous and binary outcomes. The meta-analyses on gender and race were performed using the common metric Cohen's *d*. The meta-analysis on age converted correlations into the common metric Fisher's z for analysis but uses Pearson's *r* for interpretation. In both cases, the transformed effect sizes were then weighted based on the precision of the estimate from each study. This weighting ensured that studies

Table 5 Results from ANOVA by race

	Mean (standard deviation)			ANOVA			Pairwise comparisons (*p*-values)	
	White	Black	Asian	*N*	*F*	*p*	W versus B	W versus A
Environmental presence								
Study 1	4.20 (0.60)	4.41 (0.61)	4.18 (0.78)	186	1.56	.213	.229	.984
Study 2	3.73 (0.71)	4.11 (0.65)	–	195	13.97	< .001	–	–
Study 5	3.61 (0.85)	3.97 (0.79)	3.70 (0.84)	160	2.84	.061	.048	.893
Study 6	3.94 (0.68)	4.34 (0.68)	3.86 (0.75)	176	5.15	.007	.007	.899
Social presence								
Study 1	4.62 (1.20)	4.96 (1.12)	4.87 (1.13)	186	1.42	.245	.307	.449
Study 3	4.87 (1.44)	5.67 (1.18)		168	15.06	< .001	–	–
Study 4	4.65 (1.38)	5.19 (1.45)	–	176	6.46	.012	–	–
Study 7	2.18 (1.19)	2.81 (0.40)	2.36 (0.86)	84	2.36	.101	.082	.751

When comparing individual study analyses to the associated meta-analysis, please note that omnibus ANOVA *p* values will be equivalent for single race comparisons (see studies 2, 3, and 4). However, when there are multiple racial comparisons (see studies 1, 5, 6, and 7) pairwise comparisons include a correction for multiple comparisons which will make the *p* values larger (more conservative) than the associated *p* values in the meta-analysis

with larger sample sizes and smaller standard errors have a greater impact on the overall summary estimate.

When multiple measures of presence were reported for a single study (i.e., for Study 1), we combined them into a single measure when deriving the overall effect of demographic variables. This is a conservative approach to ensure that our analyses did not assign more weight to this study simply because it has more outcome measures. Post hoc power analyses for these meta-analyses were conducted according to Valentine et al. (2010) and assumed moderate heterogeneity (moderate variation in study outcomes). For power analysis syntax see Quintana and Tiebel (2019). To explore whether the demographic differences in presence may differ for environmental vs. social presence, we conducted moderator subgroup analyses with mixed-effects models and included both outcome measures from Study 1. To explore whether the demographic differences in presence may differ between more recent research and older research, we conducted moderator subgroup analyses with mixed-effects models comparing the results of studies 1–4 with studies 5–7. Studies in the 'older' group employed VR technology that predated consumer adoption; studies in the 'newer' group employed HTC Vive VR technology. We provide a public copy of the CMAv3 datafile on OSF to allow readers to replicate these analyses (https://osf.io/pd3bk/?view_only=f305aaade1584a2a8413bee8cfa05ce2).

4.1 Age

The relationship between age and presence was generally null but occasionally negative (see Table 3). Out of the four studies that measured environmental presence, one found a significant negative relationship with age (study 2, $r = -0.16$, $p = 0.021$) and the others found no relationship. Within the four studies that measured social presence, one trended in a negative direction but did not reach statistical significance (study 5, $r = -0.21$, $p = 0.055$) and three found no relationship.

A meta-analysis found no overall relationship between age and presence ($r = -0.05$, 95% CI [-0.11, 0.02], $p = 0.171$, $k = 7$). This analysis was estimated to have 14% power to detect an effect size of this small magnitude. The null relationship between age and presence remained consistent regardless of the type of presence measured (environmental vs. social; $Q(1) = 0.007$, $p = 0.932$). There was neither a significant correlation between age and environmental presence ($r = -0.05$, $p = 0.227$, $k = 4$) nor social presence ($r = -0.05$, $p = 0.300$, $k = 4$, see Fig. 2). Subgroup moderator analyses comparing older studies (1–4) with newer studies (5–7) found no statistical difference between the strength of the relationship between age and presence based on the date the study was conducted ($Q(1) = 0.08$, $p = 0.777$). The relationship between age and presence was not significant for older studies ($r = -0.6$, $p = 0.196$), nor for newer studies ($r = -0.04$, $p = 0.093$).

4.2 Gender

The relationship between presence and gender was explored in studies 1, 5, 6, and 7, because other studies included only female participants. Gender differences in presence appeared in studies that measured environmental presence, but not those which measured social presence (see Table 4). However, the direction of the gender differences in environmental presence was inconsistent. In study 5 and study 6, women reported significantly more environmental presence

Study name	Group by Presence Type	Correlation	Lower limit	Upper limit	Z-Value	p-Value
Study1(Environmental)	Environmental	-0.080	-0.216	0.059	-1.125	0.260
Study 2	Environmental	-0.160	-0.287	-0.028	-2.366	0.018
Study 5	Environmental	-0.004	-0.147	0.139	-0.054	0.957
Study 6	Environmental	0.040	-0.103	0.181	0.547	0.584
	Environmental	-0.054	-0.141	0.034	-1.207	0.227
Study 1 (Social)	Social	-0.080	-0.216	0.059	-1.125	0.260
Study 3	Social	-0.034	-0.172	0.106	-0.476	0.634
Study 4	Social	0.050	-0.089	0.187	0.704	0.481
Study 7	Social	-0.210	-0.410	0.009	-1.883	0.060
	Social	-0.049	-0.139	0.043	-1.037	0.300

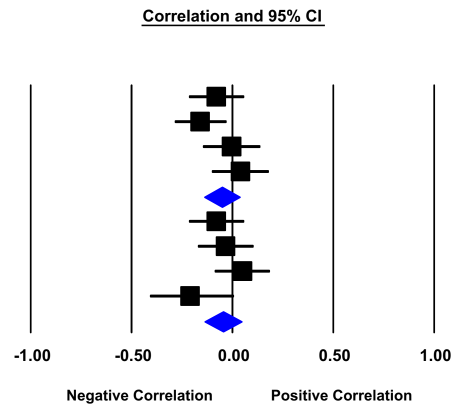


Fig. 2 Forest plot depicting the correlation between age and presence

than men (study 5, $F=4.19$, $p=0.042$; study 6, $F=9.99$, $p=0.002$), but in study 1 men reported significantly more environmental presence than women ($F=5.79$, $p=0.017$). No significant gender differences in social presence were found.

A meta-analysis found no overall difference between men and women's' reported presence ($d=0.21$, 95% CI [−0.15, 0.57], $p=0.253$, $k=4$). This analysis was estimated to have 43% power to detect an effect size of this magnitude. The null difference in men and women's presence remained consistent regardless of the type of presence measured (social vs. environmental; $Q\ (1)=0.013$, $p=0.910$). There was neither a significant difference between men and women for ratings of environmental presence ($d=0.14$, $p=0.579$, $k=3$) nor social presence ($d=0.10$, $p=0.620$, $k=2$, see Fig. 3). Subgroup moderator analyses comparing older studies (1–4) with newer studies (5–7) found a significant difference between the strength of the relationship between gender and presence based on the date the study was conducted ($Q(1)=17.77$, $p<0.001$). In more recent studies, women reported significantly more presence than men ($d=0.38$, $p<0.001$), whereas for study 1 (the only older study that included both genders), men reported more presence than women ($d=-0.21$, $p=0.039$).

4.3 Race

Out of the four studies that measured environmental presence, three found that Black participants reported higher presence than White participants (study 2, $p<0.001$; study 5, $p=0.048$; study 6, $p=0.007$) while the other found no relationship (study 1, see Table 5). Within the four studies that measured social presence, two also found that Black participants reported significantly higher presence than White participants (study 3, $p<0.001$, study 4, $p=0.012$). No differences in presence were found between White and Asian participants for any study.

Study name	Group by Presence	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Study1(Environmental)	Environmental	-0.343	0.142	0.020	-0.622	-0.064	-2.408	0.016
Study 5	Environmental	0.315	0.155	0.024	0.012	0.619	2.038	0.042
Study 6	Environmental	0.451	0.147	0.022	0.163	0.739	3.067	0.002
	Environmental	0.139	0.251	0.063	-0.352	0.631	0.555	0.579
Study 1 (Social)	Social	-0.068	0.141	0.020	-0.345	0.209	-0.481	0.631
Study 7	Social	0.353	0.232	0.054	-0.101	0.807	1.522	0.128
	Social	0.102	0.207	0.043	-0.303	0.507	0.495	0.620

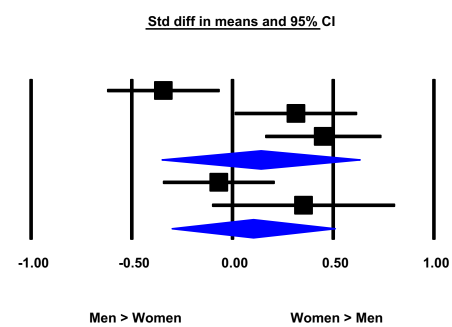


Fig. 3 Forest plot depicting standardized mean difference (Cohen's *d*) in reported presence for Women compared to Men

Two meta-analyses were conducted to determine whether there were racial differences in presence: first comparing Black and White participants, second, comparing Asian and White participants. In both of these analyses, effect sizes indicate the differences in reported presence between White participants and Black or Asian participants. Positive effect sizes indicate that non-White participants report higher levels of presence than White participants, while negative effects indicate that non-White participants report lower levels of presence than White participants.

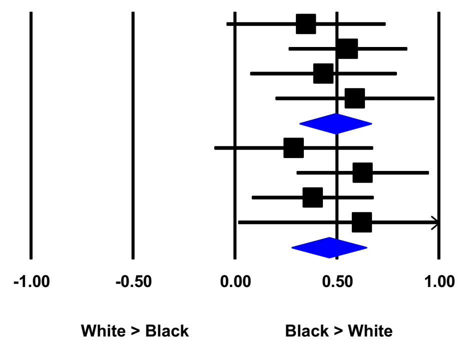
Overall, Black participants reported significantly more presence than White participants ($d = 0.50$, 95% CI [0.36, 0.63], $p < 0.001$, $k = 7$). This analysis was estimated to have 100% power to detect an effect size of this magnitude. The difference in Black and White participants' presence remained consistent regardless of the type of presence measured. Black participants reported significantly higher levels of environmental presence ($d = 0.49$, $p = < 0.001$, $k = 4$) and social presence ($d = 0.46$, $p = < 0.001$, $k = 4$) compared to White participants.

Overall, Asian participants did not report significantly different levels of presence compared to White participants ($d = 0.08$, 95% CI [−0.13, 0.29], $p = 0.464$, $k = 4$). This analysis was estimated to have 18% power to detect an effect size of this magnitude. The null difference between Asian and White participant's presence remained consistent for environmental ($d = 0.02$, $p = 0.880$, $k = 3$) and social presence ($d = 0.20$, $p = 0.172$, $k = 2$). Racial differences in presence were not moderated by the type of presence measured (social vs. environmental; $Q_{Black}(1) = 0.058$, $p = 0.810$; $Q_{Asian}(1) = 0.921$, $p = 0.337$; see Fig. 4).

Subgroup moderator analyses comparing older studies (1–4) with newer studies (5–7) found no statistical difference between the strength of the relationship between race and presence based on the date the study was conducted ($Q(1) = 0.08$, $p = 0.781$). Black participants reported more

a

Study name	Group by Presence Type	Std diff in means	Standard error	Z-Value	p-Value
Study 1 (Environmental)	Environmental	0.35	0.20	1.75	0.079
Study 2	Environmental	0.55	0.15	3.74	0.000
Study 5	Environmental	0.43	0.18	2.37	0.018
Study 6	Environmental	0.59	0.20	2.96	0.003
	Environmental	0.49	0.09	5.52	0.000
Study 1 (Social)	Social	0.29	0.20	1.45	0.147
Study 3	Social	0.63	0.17	3.79	0.000
Study 4	Social	0.38	0.15	2.51	0.012
Study 7	Social	0.62	0.31	2.01	0.044
	Social	0.46	0.09	4.95	0.000



b

Study name	Group by Presence Type	Std diff in means	Standard error	Z-Value	p-Value
Study 1 (Environmental)	Environmental	0.03	0.17	0.17	0.862
Study 5	Environmental	0.11	0.22	0.48	0.630
Study 6	Environmental	-0.12	0.25	-0.47	0.638
	Environmental	0.02	0.12	0.15	0.880
Study 1 (Social)	Social	0.21	0.17	1.21	0.225
Study 7	Social	0.17	0.26	0.64	0.521
	Social	0.20	0.15	1.37	0.172

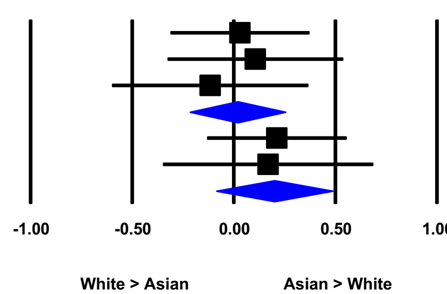


Fig. 4 **a** Forest plot depicting standardized mean difference (Cohen's *d*) in reported presence for Black participants compared to White participants. **b** Forest plot depicting the standardized mean difference (Cohen's *d*) in reported presence for Asian participants compared to White participants

presence than White participants in older studies ($d = 0.48$, $p < 0.001$), and in newer studies ($d = 0.52$, $p < 0.001$).

5 Discussion

Data from seven independent studies and associated meta-analyses revealed that, on average, participants' feelings of presence were unrelated to participants' age and gender but differed by participants' self-identified race. Black participants reported approximately half a standard deviation more presence than White participants, and this result was consistent across both social and environmental presence. To our knowledge, this is the first empirical exploration of racial differences in presence with sufficient power to find differences of this magnitude. Although our results require replication, they indicate that researchers, practitioners, and regulators may need to consider the potential for racial differences in presence when evaluating the efficacy of VR applications in future. Many VR applications require users to experience a high level of presence in order to be effective (Slater et al. 1996; Wallis and Tichon 2013; Kim and Biocca 1997; Barreda-Ángeles et al. 2020). Although the racial differences in presence reported here will not necessarily translate into differential efficacy of VR-based tools, this possibility should be explored in future experimental research.

In line with our own results, existing research on gender differences in presence has also found mixed results. An examination of existing literature suggested that women may report higher feelings of social presence and men higher environmental presence (especially in interactive VR experiences that require the manipulation of objects), although we explored this possibility within our dataset, we found no evidence for this trend. However, it is important to note that our analyses of gender were insufficiently powered because several of our samples were of women only and therefore could not be included in these particular analyses. We call upon researchers to continue to examine gender differences in presence. Given that VR research is frequently conducted with people of all genders, a systematic review and meta-analysis of existing literature appears warranted and would likely provide a more robust test of whether gender differences depend on the type of presence in question. In addition, it remains likely that other moderating variables may explain these mixed results for gender. Particularly, the specific tasks participants were completing, participant's perceived or actual competence at the tasks, or other contextual variables that we did not measure. We speculate on how the nature of the VR tasks we included may have impacted gender differences in presence in more detail below.

Also, in line with previous research, we find that the relationship between age and presence was not statistically significant, but trending negative for both social and environmental presence. Although our age analyses were powered to find a relatively small effect, our age range was often constrained to adults in their 20 s and 30 s. Therefore, our result indicating that age does not predict a significant reduction in presence is constrained to this age bracket, but we acknowledge that presence may differ far more widely in children or older adults. We call on future research to investigate differences in presence across the entire lifespan.

In addition to these constraints upon our conclusions, the data reported here were not collected with the intention of determining *why* demographic differences in presence might occur; but simply to determine whether such differences exist. There is a multitude of pathways through which age, gender, and/or race may influence people's likelihood of experiencing and reporting presence in VR. For example, attitudes toward and familiarity with the VR content (Taylor et al. 2020; Ross et al. 2006), differences in mental imagery (Iachini et al. 2019; Isaac and Marks 1994), and cultural differences in reporting tendencies (Landrine and Corral 2014). Moreover, given the correlation between demographic social constructs and physical differences in body size and proportions (e.g., gender, Stanney et al. 2020), it is possible that our social categories are simply a poor proxy for physical differences that might impact what different bodies are afforded by VR. Importantly, it is likely the case that various factors impact presence simultaneously, working together and/or in opposition with one another.

Although we did not seek to test why demographic differences in presence occur, we offer some potential theoretical explanations in the hope that future research might explore these possibilities. One potential causal mechanism is that different demographic groups are impacted differentially by cybersickness. Presence is generally negatively related to cybersickness (Weech et al. 2019) as the distracting effects of cybersickness suppress attention to the VR environment that is required for presence to occur (Witmer and Singer 1998; Usoh et al. 2000; Nichols et al. 2000). Cybersickness propensity has been found to differ by age (Petri et al. 2020; Arns and Cerney 2005; Knight and Arns 2006; although see Saredakis et al. 2020), gender (Petri et al. 2020; Gonçalves et al. 2018; Jun et al. 2020; Shafer et al. 2017; Saredakis et al. 2020), and race (Martingano et al. 2022). Given the negative relationship between cybersickness and presence, older, female, and White VR users may be at risk of experiencing less presence in VR. We find evidence consistent with these expectations for race, but not age or gender. In combination with limited power, the VR environments we used triggered very low levels of cybersickness which may limit our ability to detect demographic differences in presence. Interestingly, a recent study found that ensuring headset fit eradicated demographic differences in cybersickness (for gender at least, Stanney et al. 2020). Potentially age and racial differences in cybersickness could be similarly reduced by ensuring headsets fit diverse bodies. To the extent that demographic differences in presence may result from differences in cybersickness, examining whether eradicating cybersickness has a knock-on effect in increasing presence among at-risk groups is an interesting avenue for future research.

Another explanation for demographic differences in presence may be that different demographic groups experience different levels of emotional arousal while in VR. Previous research has indicated that presence can be increased by inducing anxiety (Bouchard et al. 2008), and so higher presence may reflect higher levels of anxiety in a given situation. It is also possible, however, that there is an optimum level of arousal for experiencing presence in VR. Following Yerkes-Dodson Law (Yerkes and Dodson 1908), too much *and* too little arousal may negatively impact the experience of presence. Although it is difficult to theorize in advance which VR environments would likely trigger the optimum level of arousal for different demographic groups, this causal mechanism would suggest that demographic differences in presence would manifest most dramatically when using tasks that are skewed in design to be more emotionally arousing for one particular gender, race, and/or age.

Although the VR experiences used in our research were not deliberately designed to be more familiar or arousing for any particular demographic group, thoughtful consideration after-the-fact yields some potential differences in this regard. Our VR clinical experience often involved interracial interactions (users were assigned to interact with a Black or White avatar, who, by chance, may have been of a different race to themselves). VR interracial interactions can be anxiety-provoking for White, Black, and Asian participants alike, albeit for different reasons (Taylor et al. 2020). It is possible that presence may be enhanced by this anxiety and perhaps disproportionately more for our Black users—who ultimately reported significantly higher levels of presence in our studies. However, it is worth noting that the racial differences in presence observed with our data do not appear to be driven only by studies that involved interracial interactions (study 1, 3, 4 and 7) as we also find them in studies involving the virtual buffet (study 2, 5, and 6) which did not involve social interaction. In the buffet, there were virtual humans representing multiple skin colors visible in the background, and however, the focal virtual human, the cashier, appeared as a White woman. This could elicit feelings of being in a White dominated space. In addition, the buffet environment, although not obviously gendered, was used in child feeding research. Users were asked to make a meal for their children using the options available. Mothers are more likely to be responsible for the day-to-day feeding decisions of children than fathers (Rahill et al. 2020) and may find this task more familiar.

In addition, because mothers generally assume this responsibility for their child's diet, they may feel more guilt and pressure to perform "well" on this task. This heightened emotional arousal may lead to higher feelings of presence in the buffet environment. In line with this theorizing, we found that women reported significantly more presence than men when using the VR buffet (study 5 and 6). Finally, all of our research studies were conducted within a US government-funded medical facility (NIH, Bethesda campus). Given historical inequities in healthcare for both women and racial minorities (e.g., Hoffman et al. 2016; Alcalde-Rubio et al. 2020), it is possible that research in this environment may have led to heightened levels of arousal in these traditionally marginalized groups.

Although the ideas discussed above are post hoc, we strongly urge VR designers and researchers to deeply evaluate whether the VR environments they are creating and their testing environments might be emotionally more arousing for specific demographic groups.

6 Importance of evaluating demographic differences in presence

Given the increased prevalence of VR for therapeutic, educational, and other 'serious' purposes, it is becoming increasingly important to ensure equity of access to this technology across demographic groups. Feelings of presence are essential to the success of many VR outcomes (e.g., Barreda-Ángeles et al. 2020; Slater et al. 1996; Triberti et al. 2014; Wallis and Tichon 2013). Therefore it is critical to ensure that presence is aroused across different ages, genders, and racial groups to provide equity of access for all. This research provides an important first step in highlighting potential areas for improvement in this regard. Of particular note, is the appearance of racial differences that occur consistently for both social presence and environmental presence. To date, racial differences in presence have been vastly under-researched, with the current study forming one of only a handful of studies that have investigated this issue. We call upon VR researchers to routinely recruit more racially diverse samples and also for researchers in this area to design studies specifically to address potential racial differences in presence as well as potential knock-on effects on the efficacy of VR interventions.

Although gender and age differences in presence have been investigated more frequently, there is also room for improvement in these areas. Much of the research on gender and age differences in presence has been conducted over a decade ago. Developments in both hardware and software in recent years may render these findings obsolete. Indeed, recent research on age differences in presence has often not replicated the differences found in earlier research (e.g., Corriveau Lecavalier et al. 2020; Mitzner et al. 2021). We found some limited suggestion that gender differences in presence may manifest differently in modern VR. However, this result is limited to a single study comparison and so requires further investigation before any concrete conclusions can be made. This result, however, highlights the importance of continued research into the potential for demographic differences in presence. Feelings of presence are the product of an interaction between VR technology, content, and user characteristics, and therefore, as the technology evolves over time, it is reasonable to assume that demographic trends in presence may also change. In response, researchers should continue to explore potential emergence of demographic differences alongside technological advancements.

7 Limitations

Our data suggest that there are significant demographic differences in presence, at least in terms of race, with Black participants reporting approximately half a standard deviation more presence than White participants. Limitations in our samples regarding gender and age (discussed above) prevent firm conclusions from being drawn regarding these null effects. But even in terms of race, there are important limitations that should be considered when interpreting our results. We excluded participants who did not identify as Asian, Black, or White from the current analyses. This decision was made to ensure we had greater power to detect racial differences in presence. However, we are therefore unable to make any conclusions about racial groups that were not well represented in our samples. Future research should attempt to oversample non-White populations to achieve a sufficient sample size for other racial comparisons. Another limitation is that we excluded individuals who identified as more than one race. This may have artificially created distinct racial groups that in reality are much less coherent and discrete. It is also worth noting that American participants represent a society that is not typical of the world's population, which limits its representativeness (Henrich et al. 2010; Rad et al. 2018), and therefore, there is no reason to expect these same racial differences would be found outside of a US context.

In addition to our sample limitations, we relied on short, self-report measures of social and environmental presence adapted from existing measures (Fox et al. 2009; Bailenson et al. 2005). Although these measures are relatively commonly used, they are not officially validated. Other more comprehensive measures of presence exist including Witmer-Singer (Witmer and Singer 1998), Slater-Usoh-Steed [SUSt, Usoh et al. (1994), ITC-Sense of Presence Inventory (Lessiter et al. 2000)]. We used the full Witmer–Singer questionnaire to measure environmental presence in study 1. This study followed the same trend as others for age and race but did differ in terms of gender. It is possible that gender or other differences in environmental presence may be measure-dependent. The Witmer–Singer measure also includes subscales (Control Factors, Sensory Factors, Distraction Factors, and Realism Factors, Witmer and Singer 1998), and potentially demographic differences in presence may occur more strongly for some of these factors than others. Future research could explore this possibility. Moreover, in future, objective measures of presence may also be possible, such as changes in heart rate (Meehan et al. 2002) or EEG signal power (Athif et al. 2020) which would reduce the possibility that demographic differences in presence are a product of reporting differences. At present, such measures still require robust validation.

8 Conclusion

In conclusion, our data provide the first indication that presence may differ by race, as well as contributing to a mixed and conflicted literature on age and gender differences in presence. Future research opportunities include a wider systematic review and meta-analysis examining each of these demographic characteristics in the existing literature. Additionally, researchers may want to explore the impact that manipulating anxiety and cybersickness levels could have on presence, with the hope that minimizing differences in these regards may have the knock-on effect of equalizing presence across groups. Keeping in mind the importance of presence for the efficacy of VR tools and experiences, it is important for future research to explore how to mitigate such differences to ensure equity in future VR interventions.

9 Disclaimer

The mention of commercial products, their sources, or their use in connection with material reported herein is not to be construed as either an actual or implied endorsement of such products by the Department of Health and Human Services.

Appendix A

See Table 6.

Table 6 Presence measures

Study	Presence	Items	Response scale
Study 1	Environmental	19 items from the Presence Questionnaire (Witmer and Singer 1998)	7-point scale
	Social	Even when my patient was present, I still felt alone in the virtual room I felt like there was someone else in the clinic room with me I felt like my patient was aware of my presence in the room	1 = strongly disagree 7 = strongly agree
Study 2	Environmental	To what extent were you involved in the virtual world? To what extent did you feel like you were inside the virtual world? To what extent did you feel surrounded by the virtual world? 4) To what extent did it feel like you visited another place? How much did the virtual world seem like the real world?	1 = Not at all, 2 = Slightly, 3 = Moderately, 4 = Very Much, 5 = Extremely
Study 3	Social	Even when the doctor was present, I still felt alone in the virtual room I felt like the doctor was in the clinic room with me I felt like the doctor was aware of my presence in the room	1 = strongly disagree 7 = strongly agree
Study 4	Social	Even when the doctor was present, I still felt alone I felt like the doctor was in the clinic room with me I felt like the doctor was aware of my presence in the room	1 = strongly disagree 7 = strongly agree
Study 5	Environmental	To what extent did you feel involved in the virtual world? To what extent did you feel like you were inside the virtual world? To what extent did you feel surrounded by the virtual world? To what extent did it feel like you visited another place? How much did the virtual world seem like the real world?	1 = Not at all, 2 = Slightly, 3 = Moderately, 4 = Very Much, 5 = Extremely
Study 6	Environmental	To what extent were you involved in the virtual world? To what extent did you feel like you were inside the virtual world? To what extent did you feel surrounded by the virtual world? To what extent did it feel like you visited another place? How much did the virtual world seem like the real world?	1 = Not at all, 2 = Slightly, 3 = Moderately, 4 = Very Much, 5 = Extremely
Study 7	Social	Even when my patient was present, I still felt alone in the virtual room I felt like there was someone else in the clinic room with me I felt like my patient was aware of my presence in the room	Agree/disagree

Acknowledgements This work was supported by the Intramural Research Program of the National Genome Research Institute.

Data availability The datasets generated during and/or analyzed during the current study are available in the OSF repository, https://osf.io/pd3bk/?view_only=f305aaade1584a2a8413bee8cfa05ce2.

Declarations

Ethical approval All studies received appropriate IRB approval.

Conflict of interest We have no known competing interests to disclose.

References

Alcalde-Rubio L, Hernández-Aguado I, Parker LA, Bueno-Vergara E, Chilet-Rosell E (2020) Gender disparities in clinical practice: are there any solutions? Scoping review of interventions to overcome or reduce gender bias in clinical practice. Int J Equity Health 19(1):1–8. https://doi.org/10.1186/s12939-020-01283-4

Almog I, Wallach HS, Safir MP (2009) Ethnicity and sense of presence in a virtual environment: Arab women: a case in point. Accepted for publication in Virtual Rehabilitation 2009 International Conference proceedings

Arns LL, Cerney MM (2005) The relationship between age and incidence of cybersickness among immersive environment users. IEEE Proc. https://doi.org/10.1145/1140491.1140539

Athif M, Rathnayake BLK, Nagahapitiya SDBS, Samarasinghe SAK, Samaratunga PS, Peiris RL, De Silva AC (2020) Using biosignals for objective measurement of presence in virtual reality environments. In: 2020 42nd annual international conference of the IEEE engineering in medicine and biology society (EMBC) (pp. 3035–3039). IEEE

Ausburn L, Ausburn F (2008) Effects of desktop virtual reality on learner performance and confidence in environment mastery: opening a line of inquiry. J STEM Teacher Educ 45(1):6

Bailenson JN, Swinth K, Hoyt C, Persky S, Dimov A, Blascovich J (2005) The independent and interactive effects of embodied-agent appearance and behavior on self-report, cognitive, and behavioral markers of copresence in immersive virtual environments. Presence Teleoper Virtual Environ 14(4):379–393. https://doi.org/10.1162/105474605774785235

Bailey J, Bailenson JN, Won AS, Flora J, Armel KC (2012) Presence and memory: immersive virtual reality effects on cued recall. In: Proceedings of the international society for presence research annual conference. October 24–26, Philadelphia, Pennsylvania, USA

Baños RM, Quero S, Salvador S, Botella C (2005) The role of presence and reality judgment in virtual environments in clinical psychology. In: Bullinger A, Wiederhold B, Meise U, Mueller-Spahn F (eds) Applied technologies in medicine and neuroscience. Verlag Integrative Psychiatrie, Innsbruck, pp 21–30

Barreda-Ángeles M, Aleix-Guillaume S, Pereda-Baños A (2020) An "empathy machine" or a "just-for-the-fun-of-it" machine? Effects of immersion in nonfiction 360-video stories on empathy and enjoyment. Cyberpsychol Behav Soc Netw 23(10):683–688. https://doi.org/10.1089/cyber.2019.0665

Baus O, Bouchard S (2014) Moving from virtual reality exposure-based therapy to augmented reality exposure-based therapy: a review. Front Hum Neurosci. https://doi.org/10.3389/fnhum.2014.00112

Beverly EA, Love C, Love M, Williams E, Bowditch J (2021) Using virtual reality to improve health care providers' cultural self-efficacy and diabetes attitudes: pilot questionnaire study. JMIR Diab 6(1):e23708. https://doi.org/10.2196/23708

Biocca F (2006) The cyborg's dilemma: progressive embodiment in virtual environments. J Comput Mediat Commun. https://doi.org/10.1111/j.1083-6101.1997.tb00070.x

Biocca F, Harms C, Burgoon JK (2003) Toward a more robust theory and measure of social presence: review and suggested criteria. Presence Teleoper Virtual Environ 12(5):456–480. https://doi.org/10.1162/105474603322761270

Blackwell L, Ellison N, Elliott-Deflo N, Schwartz R (2019) Harassment in social virtual reality: challenges for platform governance. Proc ACM Hum Comput Interact 3(100):1–25. https://doi.org/10.1145/3359202

Blascovich J (2002) Social influence within immersive virtual environments. Social Life Avatars. https://doi.org/10.1007/978-1-4471-0277-9_8

Borenstein M, Hedges LV, Higgins JPT, Rothstein HR (2006) Comprehensive meta-analysis. Biostat, Englewood

Bouchard S, St-Jacques J, Robillard G, Renaud P (2008) Anxiety increases the feeling of presence in virtual reality. Presence Teleoper Virtual Environ 17(4):376–391. https://doi.org/10.1162/pres.17.4.376

Bowman DA, McMahan RP (2007) Virtual reality: how much immersion is enough. Computer. https://doi.org/10.1109/MC.2007.257

Carvalho MRD, Freire RC, Nardi AE (2010) Virtual reality as a mechanism for exposure therapy. World J Biol Psychiatry 11(2–2):220–230. https://doi.org/10.3109/15622970802575985

Chang CW, Li M, Yeh SC, Chen Y, Rizzo A (2020) Examining the effects of HMDs/FSDs and gender differences on cognitive processing ability and user experience of the Stroop task-embedded virtual reality driving system (STEVRDS). IEEE Access 8:69566–69578

Chirico A, Lucidi F, De Laurentiis M, Milanese C, Napoli A, Giordano A (2016) Virtual reality in health system: beyond entertainment: a mini-review on the efficacy of VR during cancer treatment. J Cell Physiol 231(2):275–287. https://doi.org/10.1002/jcp.25117

Cho YH, Yim SY, Paik S (2015) Physical and social presence in 3D virtual role-play for pre-service teachers. Internet Higher Educ 25:70–77. https://doi.org/10.1016/j.iheduc.2015.01.002

Clifton J, Palmisano S (2020) Effects of steering locomotion and teleporting on cybersickness and presence in HMD-based virtual reality. Virtual Real 24(3):453–468. https://doi.org/10.1007/s10055-019-00407-8

Coburn JQ, Freeman I, Salmon JL (2017) A review of the capabilities of current low-cost virtual reality technology and its potential to enhance the design process. J Comput Inf Sci Eng. https://doi.org/10.1115/1.4036921

Corriveau Lecavalier N, Ouellet É, Boller B, Belleville S (2020) Use of immersive virtual reality to assess episodic memory: a validation study in older adults. Neuropsychol Rehabil 30(3):462–480. https://doi.org/10.1080/09602011.2018.1477684

Cummings JJ, Bailenson JN (2016) How immersive is enough? A meta-analysis of the effect of immersive technology on user presence. Media Psychol 19(2):272–309. https://doi.org/10.1080/15213269.2015.1015740

De Leo G, Diggs LA, Radici E, Mastaglio TW (2014) Measuring sense of presence and user characteristics to predict effective training in an online simulated virtual environment. Simul Healthc 9(1):1–6. https://doi.org/10.1097/sih.0b013e3182a99dd9

DerSimonian R, Laird N (1986) Meta-analysis in clinical trials. Control Clin Trials 7:177–188

Dilanchian AT, Andringa R, Boot WR (2021) A pilot study exploring age differences in presence, workload, and cybersickness in the experience of immersive virtual reality environments. Front Virtual Real 2:736793. https://doi.org/10.3389/frvir.2021.736793

Duane JN, Stosic M, Ericson J, Durieux B, Sanders J, Robicheaux E, Blanch-Hartigan D (2022) The virtual doctor is in: the effect of telehealth visits on patient experience. In: Proceedings of the 55th Hawaii International Conference on System Sciences. http://hdl.handle.net/10125/79804

Felnhofer A, Kothgassner OD, Hauk N, Beutl L, Hlavacs H, Kryspin-Exner I (2014) Physical and social presence in collaborative virtual environments: exploring age and gender differences with respect to empathy. Comput Hum Behav 31:272–279. https://doi.org/10.1016/j.chb.2013.10.045

Felnhofer A, Kothgassner OD, Beutl L, Hlavacs H, Kryspin-Exner I (2012) Is virtual reality made for men only? Exploring gender differences in the sense of presence. In: Proceedings of the international society on presence research. 103–112

Felton WM, Jackson RE (2021) Presence: a review. Int J Hum Comput Interact 38(1):1–18. https://doi.org/10.1080/10447318.2021.1921368

Fox J, Bailenson J, Binney J (2009) Virtual experiences, physical behaviors: the effect of presence on imitation of an eating avatar. Presence Teleop Virt Environ 18:294–303. https://doi.org/10.1162/pres.18.4.294

Freina L, Ott M (2015) A literature review on immersive virtual reality in education: state of the art and perspectives. In: The

international scientific conference elearning and software for education. 1(133): 10–1007
Gamito P, Oliveira J, Santos P, Morais D, Saraiva T, Pombal M, Mota B (2008) Presence, immersion and cybersickness assessment through a test anxiety virtual environment. Annu Rev Cyberther Telemed 6:83–90
Garau M, Slater M, Pertaub D-P, Razzaque S (2005) The responses of people to virtual humans in an immersive virtual environment. Presence Teleoper Virtual Environ 14(1):104–116. https://doi.org/10.1162/1054746053890242
Garrison DR, Cleveland-Innes M, Fung TS (2010) Exploring causal relationships among teaching, cognitive and social presence: student perceptions of the community of inquiry framework. Internet Higher Educ 13(1–2):31–36. https://doi.org/10.1016/j.iheduc.2009.10.002
Giannopoulos E, Eslava V, Oyarzabal M, Hierro T, González L, Ferre M et al (2008) The effect of haptic feedback on basic social interaction within shared virtual environments, in Haptics: PERCEPTION, Devices and Scenarios. Springer, Berlin
Gonçalves G, Melo M, Bessa M (2018) Virtual reality games: a study about the level of interaction vs. Narrative and the gender in presence and cybersickness. In: 2018 International conference on graphics and interaction (ICGI) (pp. 1–8). IEEE
Grassini S, Laumann K, Luzi AK (2021) Association of individual factors with simulator sickness and sense of presence in virtual reality mediated by head-mounted displays (HMDs). Multimodal Technol Interact 5(3):7. https://doi.org/10.3390/mti5030007
Hauber J, Regenbrecht H, Hills A, Cockburn A, Billinghurst M (2005) Social presence in two-and three-dimensional videoconferencing. In: Proceedings of 8th annual international workshop on presence (London)
Heeter C (1992) Being there: the subjective experience of presence. Presence Teleoper Virtual Environ 1(2):262–271. https://doi.org/10.1162/pres.1992.1.2.262
Henrich J, Heine SJ, Norenzayan A (2010) Beyond WEIRD: towards a broad-based behavioral science. Behav Brain Sci 33(2–3):111. https://doi.org/10.1017/S0140525X10000725
Hernandez R, Burrows B, Browning MH, Solai K, Fast D, Litbarg NO, Litbarg NO, Wilund KR, Moskowitz JT (2021) Mindfulness-based virtual reality intervention in hemodialysis patients: a pilot study on end-user perceptions and safety. Kidney 360 2(3):435. https://doi.org/10.34067/KID.0005522020
Hite RL, Jones MG, Childers GM, Ennes M, Chesnutt K, Pereyra M, Cayton E (2019) Investigating potential relationships between adolescents' cognitive development and perceptions of presence in 3-D, haptic-enabled, virtual reality science instruction. J Sci Educ Technol 28(3):265–284. https://doi.org/10.1007/s10956-018-9764-y
Hodges LF, Kooper R, Meyer TC, Rothbaum BO, Opdyke D, deGraaff JJ, North MM (1995) Virtual environments for treating the fear of heights. Computer 28(7):27–34. https://doi.org/10.1109/2.391038
Hoffman KM, Trawalter S, Axt JR, Oliver MN (2016) Racial bias in pain assessment and treatment recommendations, and false beliefs about biological differences between blacks and whites. Proc Natl Acad Sci 113(16):4296–4301. https://doi.org/10.1073/pnas.1516047113
Iachini T, Maffei L, Masullo M, Senese VP, Rapuano M, Pascale A, Ruggiero G (2019) The experience of virtual reality: are individual differences in mental imagery associated with sense of presence? Cognit Process 20(3):291–298. https://doi.org/10.1007/s10339-018-0897-y
IJsselsteijn WA (2004) Presence in depth. Technische Universiteit Eindhoven, Eindhoven
IJsselsteijn WA, de Ridder H, Freeman J, Avons SE (2000) Presence: concept, determinants and measurement. In: BE Rogowitz, TN Pappas (Eds.), Human Vision and Electronic Imaging V, January 24–27, 2000, San Jose, USA. pp. 520–529. (Proceedings of SPIE; Vol. 3959). SPIE
Isaac AR, Marks DF (1994) Individual differences in mental imagery experience: developmental changes and specialization. Br J Psychol 85(4):479–500. https://doi.org/10.1111/j.2044-8295.1994.tb02536.x
Johnson RD (2011) Gender differences in E-learning. J Org End User Comput 23(1):79–94. https://doi.org/10.4018/joeuc.2011010105
Jun H, Miller MR, Herrera F, Reeves B, Bailenson JN (2020) Stimulus sampling with 360-videos: examining head movements, arousal, presence, simulator sickness, and preference on a large sample of participants and videos. IEEE Trans Affect Comput. https://doi.org/10.1109/TAFFC.2020.3004617
Khashe S, Becerik-Gerber B, Lucas G, Gratch J (2018) Persuasive effects of immersion in virtual environments for measuring pro-environmental behaviors. Proc Int Symp Autom Robot Constr. https://doi.org/10.22260/isarc2018/0167
Kim T, Biocca F (1997) Telepresence via television: two dimensions of telepresence may have different connections to memory and persuasion. J Comput Mediat Commun. https://doi.org/10.1111/j.1083-6101.1997.tb00073.x
Kim J, Kim H, Tay BK, Muniyandi M, Srinivasan MA, Jordan J, Mortensen J, Oliveira M, Slater M (2004) Transatlantic touch: a study of haptic collaboration over long distance. Presence Teleoper Virtual Environ 13(3):328–337. https://doi.org/10.1162/1054746041422370
Knight MM, Arns LL (2006) The relationship among age and other factors on incidence of cybersickness in immersive environment users. In: Proceedings of the 3rd symposium on applied perception in graphics and visualization. pp. 162–162. https://doi.org/10.1145/1140491.1140539
Lachlan K, Krcmar M (2011) Experiencing presence in video games: the role of presence tendencies, game experience, gender, and time spent in play. Commun Res Rep 28(1):27–31. https://doi.org/10.1080/08824096.2010.518924
Landrine H, Corral I (2014) Advancing research on racial–ethnic health disparities: improving measurement equivalence in studies with diverse samples. Front Public Health 2:282. https://doi.org/10.3389/fpubh.2014.00282
Lee KM (2004) Presence, explicated. Commun Theory 14(1):27–50. https://doi.org/10.1111/j.1468-2885.2004.tb00302.x
Lee JER, Park SW (2011) Whose second life is this?" How avatar-based racial cues shape ethno-racial minorities' perception of virtual worlds. Cyberpsychology Behav Social Netw. https://doi.org/10.1089/cyber.2010.0501
Lessiter J, Freeman J, Keogh E, Davidoff J (2000) Development of a new cross-media presence questionnaire: the ITC-sense of presence inventory. In: Proceedings of PRESENCE
Lim J, Richardson JC (2016) Exploring the effects of students' social networking experience on social presence and perceptions of using SNSs for educational purposes. Internet Higher Educ 29:31–39. https://doi.org/10.1016/j.iheduc.2015.12.001
Lin M-C, Tutwiler MS, Chang CY (2011) Exploring the relationship between virtual learning environment preference, use, and learning outcomes in 10th grade earth science students. Learn Media Technol 36(4):399–417. https://doi.org/10.1080/17439884.2011.629660
Ling Y, Nefs HT, Brinkman WP, Qu C, Heynderickx I (2013) The relationship between individual characteristics and experienced presence. Comput Hum Behav 29(4):1519–1530. https://doi.org/10.1016/j.chb.2012.12.010

Lombard M, Ditton T (1997) At the heart of it all: the concept of presence. J Comput Mediat Commun. https://doi.org/10.1111/j.1083-6101.1997.tb00072.x

Lombard M, Jones MT (2015) Defining presence. Immersed in media. Springer, pp 13–34

Martingano AJ, Brown E, Telaak SH, Dolwick AP, Persky S (2022) Cybersickness variability by race: findings from 6 studies and a mini meta-analysis. J Med Internet Res 24(6):e36843. https://doi.org/10.2196/36843

Meehan M, Insko B, Whitton M, Brooks FP Jr (2002) Physiological measures of presence in stressful virtual environments. Acm Trans Graph 21(3):645–652. https://doi.org/10.1145/566654.566630

Melo M, Coelho H, Gonçalves G, Losada N, Jorge F, Teixeira MS, Bessa M (2022) Immersive multisensory virtual reality technologies for virtual tourism: a study of the user's sense of presence, satisfaction, emotions, and attitudes. Multimedia Syst 28(3):1027–1037. https://doi.org/10.1007/s00530-022-00898-7

Melo M, Gonçalves G, Narciso D, Bessa M (2021) Impact of different role types and gender on presence and cybersickness in immersive virtual reality setups. In: 2021 International conference on graphics and interaction (ICGI) (pp. 1–8). IEEE

Mitzner TL, McGlynn SA, Rogers WA (2021) Understanding special presence formation and maintenance in virtual reality for younger and older adults. Gerontechnology 20(2):1–14. https://doi.org/10.4017/gt.2021.20.2.456.12

Mousas C, Anastasiou D, Spantidi O (2018) The effects of appearance and motion of virtual characters on emotional reactivity. Comput Hum Behav 86:99–108. https://doi.org/10.1016/j.chb.2018.04.036

Mujber TS, Szecsi T, Hashmi MS (2004) Virtual reality applications in manufacturing process simulation. J Mater Process Technol 155:1834–1838. https://doi.org/10.1016/j.jmatprotec.2004.04.401

Nichols S, Haldane C, Wilson JR (2000) Measurement of presence and its consequences in virtual environments. Int J Hum Comput Stud 52(3):471–491. https://doi.org/10.1006/ijhc.1999.0343

Oh CS, Bailenson JN, Welch GF (2018) A systematic review of social presence: definition, antecedents, and implications. Front Robot AI. https://doi.org/10.3389/frobt.2018.00114

Pallavicini F, Pepe A, Minissi ME (2019) Gaming in virtual reality: what changes in terms of usability, emotional response and sense of presence compared to non-immersive video games? Simul Gaming 50(2):136–159. https://doi.org/10.1177/1046878119831420

Paquay M, Goffoy J, Chevalier S, Servotte JC, Ghuysen A (2022) Relationships between internal factors, social factors and the sense of presence in virtual reality-based simulations. Clin Simul Nurs 62:1–11. https://doi.org/10.1016/j.ecns.2021.09.006

Parsons TD, Rizzo AA (2008) Affective outcomes of virtual reality exposure therapy for anxiety and specific phobias: a meta-analysis. J Behav Ther Exp Psychiatry 39(3):250–261. https://doi.org/10.1016/j.jbtep.2007.07.007

Parsons T, Gaggioli A, Riva G (2017) Virtual reality for research in social neuroscience. Brain Sci 7(12):42. https://doi.org/10.3390/brainsci7040042

Persky S, Goldring MR, Turner SA, Cohen RW, Kistler WD (2018) Validity of assessing child feeding with virtual reality. Appetite 123:201–207. https://doi.org/10.1016/j.appet.2017.12.007

Petri K, Feuerstein K, Folster S, Bariszlovich F, Witte K (2020) Effects of age, gender, familiarity with the content, and exposure time on cybersickness in immersive head-mounted display based virtual reality. Am J Biomed Sci. https://doi.org/10.5099/aj2002001

Quintana DS, Tiebel J (2019) How to calculate statistical power for your meta-analysis. https://doi.org/10.17605/OSF.IO/5C7UZ

Rad MS, Martingano AJ, Ginges J (2018) Toward a psychology of Homo sapiens: making psychological science more representative of the human population. Proc Natl Acad Sci 115(45):11401–11405. https://doi.org/10.1073/pnas.1721165115

Rahill S, Kennedy A, Kearney J (2020) A review of the influence of fathers on children's eating behaviours and dietary intake. Appetite 147:104540. https://doi.org/10.1016/j.appet.2019.104540

Richardson J, Swan K (2003) Examining social presence in online courses in relation to students' perceived learning and satisfaction. www.ideals.illinois.edu. http://hdl.handle.net/2142/18713

Rivers DC, Meade AW, Lou Fuller W (2009) Examining question and context effects in organization survey data using item response theory. Organ Res Methods 12(3):529–553. https://doi.org/10.1177/1094428108315864

Ross SP, Skelton RW, Mueller SC (2006) Gender differences in spatial navigation in virtual space: implications when using virtual environments in instruction and assessment. Virtual Real 10(3–4):175–184. https://doi.org/10.1007/s10055-006-0041-7

Sagnier C, Loup-Escande E, Valléry G (2019) Effects of gender and prior experience in immersive user experience with virtual reality. In: International conference on applied human factors and ergonomics (pp. 305–314). Springer, Cham

Saredakis D, Szpak A, Birckhead B, Keage HAD, Rizzo A, Loetscher T (2020) Factors associated with virtual reality sickness in head-mounted displays: a systematic review and meta-analysis. Front Hum Neurosci. https://doi.org/10.3389/fnhum.2020.00096

Scavarelli A, Arya A, Teather RJ (2020) Virtual reality and augmented reality in social learning spaces: a literature review. Virtual Real. https://doi.org/10.1007/s10055-020-00444-8

de Almeida Scheibler C, Rodrigues MA (2018) User experience in games with HMD glasses through first and third person viewpoints with emphasis on embodiment. In: 2018 20th symposium on virtual and augmented reality (SVR). https://doi.org/10.1109/svr.2018.00022

Schifter CC, Ketelhut DJ, Nelson BC (2012) Presence and middle school students' participation in a virtual game environment to assess science inquiry. Educ Technol Soc 15(1):53–63

Schubert TW (2009) A new conception of spatial presence: once again, with feeling. Commun Theory 19(2):161–187. https://doi.org/10.1111/j.1468-2885.2009.01340.x

Schuemie MJ, van der Straaten P, Krijn M, van der Mast CAPG (2001) Research on presence in virtual reality: a survey. Cyberpsychol Behav 4(2):183–201. https://doi.org/10.1089/109493101300117884

Schwind V, Knierim P, Tasci C, Franczak P, Haas N, Henze N (2017) These are not my hands! Effect of gender on the perception of avatar hands in virtual reality. In: Proceedings of the 2017 CHI conference on human factors in computing systems (pp. 1577–1582). https://doi.org/10.1145/3025453.3025602

Shafer DM, Carbonara CP, Korpi MF (2017) Modern virtual reality technology: cybersickness, sense of presence, and gender. Media Psychol Rev 11(2):1

Short J, Williams E, Christie B (1976) The social psychology of telecommunications. Wiley, Hoboken

Siriaraya P, Siang Ang C (2012) Age differences in the perception of social presence in the use of 3D virtual world for social interactionq. Interact Comput 24(4):280–291. https://doi.org/10.1016/j.intcom.2012.03.003

Slater M (2009) Place illusion and plausibility can lead to realistic behaviour in immersive virtual environments. Philos Trans R Soc b Biol Sci 364(1535):3549–3557. https://doi.org/10.1098/rstb.2009.0138

Slater M, Wilbur S (1997) A framework for immersive virtual environments (FIVE): speculations on the role of presence in virtual environments. Presence Teleoper Virtual Environ 6(6):603–616. https://doi.org/10.1162/pres.1997.6.6.603

Slater M, Usoh M, Steed A (1994) Depth of presence in virtual environments. Presence Teleoper Virtual Environ 3:130–144
Slater M, McCarthy J, Maringelli F (1998a) The influence of body movement on subjective presence in virtual environments. Hum Factors J Hum Factors Ergon Soc 40(3):469–477. https://doi.org/10.1518/001872098779591368
Slater M, McCarthy J, Maringelli F (1998b) The influence of body movement on subjective presence in virtual environments. Hum Factors 40(3):469–477. https://doi.org/10.1518/001872098779591368
Slater M, Linakis V, Usoh M, Kooper R, Street G (1996) Immersion, presence, and performance in virtual environments: an experiment with tri-dimensional chess. In: Paper presented at the ACM virtual reality software and technology (VRST)
Stanney K, Fidopiastis C, Foster L (2020) Virtual reality is sexist: but it does not have to be. Front Robot AI 7:4. https://doi.org/10.3389/frobt.2020.00004
Taylor VJ, Valladares JJ, Siepser C, Yantis C (2020) Interracial contact in virtual reality: best practices. Policy Insights Behav Brain Sci 7(2):132–140. https://doi.org/10.1177/2372732220943638
Triberti S, Repetto C, Riva G (2014) Psychological factors influencing the effectiveness of virtual reality–based analgesia: a systematic review. Cyberpsychol Behav Soc Netw 17(6):335–345. https://doi.org/10.1089/cyber.2014.0054
Usoh M, Catena E, Arman S, Slater M (2000) Using presence questionnaires in reality. Presence 9(5):497–503. https://doi.org/10.1162/105474600566989
Valentine JC, Pigott TD, Rothstein HR (2010) How many studies do you need? A primer on statistical power for meta-analysis. J Educ Behav Stat 35(2):215–247. https://doi.org/10.3102/1076998609346961
van Schaik P, Turnbull T, van Wersch A, Drummond S (2004) Presence within a mixed reality environment. Cyberpsychol Behav 7(5):540–552. https://doi.org/10.1089/cpb.2004.7.540
Wallach HS, Safir MP, Samana R (2010) Personality variables and presence. Virtual Real 14:3–13. https://doi.org/10.1007/s10055-009-0124-3
Wallis G, Tichon J (2013) Predicting the efficacy of simulator-based training using a perceptual judgment task versus questionnaire-based measures of presence. Presence Teleoperators Virtual Environ 22(1):67–85. https://doi.org/10.1162/PRES_a_00135
Weech S, Kenny S, Barnett-Cowan M (2019) Presence and cybersickness in virtual reality are negatively related: a review. Front Psychol 10:158. https://doi.org/10.3389/fpsyg.2019.00158
Weech S, Kenny S, Lenizky M, Barnett-Cowan M (2020) Narrative and gaming experience interact to affect presence and cybersickness in virtual reality. Int J Hum Comput Stud 138:102398. https://doi.org/10.1016/j.ijhcs.2020.102398
Wei C-W, ChenKinshuk N-S (2012) A model for social presence in online classrooms. Educ Tech Research Dev 60(3):529–545. https://doi.org/10.1007/s11423-012-9234-9
Witmer BG, Singer MJ (1998) Measuring presence in virtual environments: a presence questionnaire. Presence 7(3):225–240. https://doi.org/10.1162/105474698565686
Yerkes RM, Dodson JD (1908) The relation of strength of stimulus to rapidity of habit-formation. J Comp Neurol Psychol 18:459