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A Pilot Study Exploring Age Differences in Presence, Workload, and Cybersickness in the Experience of Immersive Virtual Reality Environments

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Research is often focused on understanding barriers to the use and adoption of technology to support older adults' (65+) instrumental activities of daily living (IADLs), such as communication, banking, and transportation. Less attention is paid to technology to support enhanced activities of daily living (EADLs), activities that enrich our daily lives, even though they have the potential to improve wellbeing, promote physical and emotional health, and reduce stress. Here, we explored how older adults interacted with commercial virtual reality (VR) to investigate the feasibility of using VR as an EADL support system. Older adults navigated different VR environments, including environments that were meditation, exploration, and game-oriented. Of particular interest was whether older adults (N = 20) psychologically experienced differing degrees of presence within virtual environments compared to younger adults (N = 20), and potential barriers to use as assessed by measures of workload and system usability. Given previously observed age-related differences in cybersickness, this was also assessed as a potential barrier. Compared to younger adults, older adults expressed a greater sense of presence in virtual environments, with nonsignificant differences in perceived workload and usability according to most measures. Contrary to expectations, older adults reported significantly less cybersickness compared to younger adults. Results suggest that VR is a promising means to support older adults' EADLs.

Keywords: virtual reality, technology adoption, usability, aging, human factors

INTRODUCTION

The Potential of Technology to Support Older Adults

Technology has potential to support older adults' Instrumental Activities of Daily Living (IADLs), activities crucial for independence, such as managing finances, household tasks, and healthcare activities (Charness and Boot, 2009; Horgas and Abowd, 2004; Ramprasad et al., 2019). However, there has been considerably less attention paid to the potential of technologies to support older adults' participation in enrichment activities, or as Rogers et al. (1998) called them, Enhanced Activities of Daily Living (EADLs). EADLs encompass hobbies, leisure, entertainment, and relaxation activities. A lack of attention to technology to support EADLs has the potential to "lock out" many older adults from enjoyable and rewarding experiences and is further unfortunate because EADLs may play a significant role in the health, well-being, and quality of life of older adults (Hughes et al., 2010; Kuykendall et al., 2015; Menec, 2003).

A host of barriers can possibly preclude meaningful interactions with technology to support IADLs and EADLs when technology is not designed considering the needs, preferences, abilities, and experiences of older user and when older adults are not included in the design process (Czaja et al., 2019). By understanding older adults' perceptions of technology and barriers to adoption, technology can be better designed to encourage technology adoption and use to benefit all activities of daily living, including EADLs (Charness and Boot, 2009). The current report investigated how older adults interacted with a relatively novel—and increasingly prevalent—form of technology to support EADLs: consumer immersive virtual reality (VR) technology.[1] Of particular interest was whether older adults psychologically experienced presence differently within virtual environments compared to younger adults, as this is one of the defining characteristics of this technology, and potential barriers to use as assessed by measures of workload and system usability.

Age Specific Barriers of Virtual Reality Adoption

Recent literature on VR to support IADL activities of older adults suggests that cybersickness, system workload and usability issues (i.e., frustration, fatigue, discomfort), and lack of experience with technology are potential barriers relevant to older adults' adoption of VR technology (Appel et al., 2020; Huygelier et al., 2019; Lee et al., 2019; Saredakis et al., 2020; Winter et al., 2021; Yen and Chiu, 2021). These issues are also likely relevant to the use of VR to support EADL activities among older adults. Additional insights into VR to support EADL activities may be gained from investigations of older adults' interactions with another common technology to support leisure: non-immersive video games. The difference between younger and older adults with respect to video game adoption and gameplay is likely due to differences in perceived needs, attitudes, perceptions, and usability barriers. In the United States, only 24% of older adults (ages 65+) report playing video games, compared to 60% of the youngest adult cohort (18–29 years old, Brown, 2017). While 30% of younger adults report playing video games frequently, only 11% of older adults report the same. This may in part be due to video games being designed by younger people for younger people, not considering the knowledge and abilities of older adults (for review, see Boot et al., 2020). For example, the challenge that video games provide may be appropriate for, and enjoyable by, younger gamers, but may frustrate older adult gamers experiencing age-related perceptual and cognitive changes. Game design can also fail to consider that inexperienced older gamers may lack the mental models required to succeed in video games (Harrington et al., 2017). Finally, attitudinal barriers may also play an important role with some older adults perceiving that video games are unimportant or are afraid that they might be perceived as childish by their peers for engaging in video game play (De Schutter et al., 2015). These challenges may also exist when older adults interact with immersive VR and perhaps prevent them from reaping the various benefits of such technologies.

Exploring Age Differences in Virtual Reality Experiences

The goal of the current investigation was to better understand older adults' perceptions of VR environments and VR technology. Of primary interest was sense of presence as this is "the defining aspect of a successful VR experience" (Weech et al., 2019). We define "presence" as the "subjective sense of being in a virtual environment" (Schubert, 2003). Measures of workload were also collected to assess potential usability barriers when navigating virtual environments as current literature suggests this to be of relevance pertaining to older adults' adoption of VR technology (Appel et al., 2020; Huygelier et al., 2019; Lee et al., 2019; Saredakis et al., 2020; Winter et al., 2021; Yen and Chiu, 2021).

Finally, cybersickness is still a relevant phenomenon to consider in the use of modern consumer VR technology (Yildirim, 2020). Because cybersickness has been identified as a potential barrier to the use of virtual reality in older adult populations (Seifert and Schlomann, 2021), perhaps more so for older adults compared to younger adults (Diersch and Wolbers 2019), it was also assessed. Age effects were of interest in part due to literature suggesting that older adults are more sensitive to simulator or cybersickness (Brooks et al., 2010; Kawano et al., 2016; Keshavarz et al., 2018). However, the relationship between age and cybersickness may be complex, as indicated by a recent meta-analysis finding that participant samples that were on average under the age of 35 generally report higher sickness compared to samples over the age of 35 (Saredakis et al., 2020). Gender may be another relevant factor to consider in the evaluation of VR experiences as older women may be especially susceptible to simulator/cybersickness (Classen et al., 2011; Park et al., 2006; Matas et al., 2015). However, it should also be noted that gender effects in the literature are inconsistent (for review, see Weech et al., 2019).

PREDICTIONS

No explicit hypotheses were developed regarding whether older adults would experience less, equal, or greater presence compared to younger adults. However, large differences in presence would have important implications for the successful implementation of VR to support EADLs of older adults. Since older adults tend to experience greater difficulty with a range of technologies (e.g., Boot et al., 2015; Roque and Boot, 2018), and have less experience with game technologies (Boot et al., 2020), workload and usability measures were also of interest. Our initial hypothesis considered large differences in workload and usability unlikely given that for many younger

[1]Virtual reality in this manuscript refers to current consumer head-mounted display (HMD) technology (HTC Vive, Oculus Rift, Valve Index, etc.).

and older adults, VR is a novel technology that would require new learning regardless of age. Finally, based on the reviewed (albeit mixed) literature on simulator and cybersickness, we initially predicted that older adults would experience greater cybersickness. In summary, the reported study investigated the feasibility of VR systems to support older adults' EADL activities by examining age differences in known and potentially important factors that may serve as barriers to adoption, use, and positive experience.

METHODS

Participants

Forty adults living in the Tallahassee region participated: twenty younger adults (M = 19.7 years, SD = 1.25; 14 females)[2] and twenty older adults (M = 71.3 years, SD = 7.41; 9 females). As this was a thesis project, sample size was largely determined by available time and resources. Younger adults were undergraduate students and were recruited through the psychology participant pool at Florida State University. Older adults were recruited through the Institute for Successful Longevity's (https://isl.fsu.edu/) participant registry. This registry contains contact information for community members in Tallahassee and surrounding areas who have indicated interest in participating in research. All participants were compensated $20 for their participation in a session that lasted approximately 2 hours. Consent was obtained by having participants read and sign a printed consent form after the nature of the study was explained to them. This study complied with APA ethical standards in the treatment of human participants and was approved by the Florida State University Human Subjects Committee (HSC No. 2018.25327).

MATERIALS AND PROCEDURES

An HTC Vive headset was used for this study. In total, participants experienced four different VR environments in a fixed order: SteamVR Home, Vesper Peak, Meditation VR, and Xortex. Participants spent 5 minutes within each environment, except Xortex, which was experienced for 3 min. They were also asked to complete surveys before the first experience, after each experience, and at the conclusion of all VR experiences. Participants were seated for all scenarios in a rolling chair that allowed them to freely swivel to see the full environment around them. While the chair could roll, participants were encouraged to stay in the center of the play-space. An experimenter remained present in the room to support the participant if the headset cord became tangled or reposition the participant if they approached an obstacle (wall, desk, computer, etc.). For the full protocol and script, see the OSF entry (https://osf.io/vkxde/?view_only=5e36543a3891498da1eeb9a3495698b2, Virtual Reality Study Protocol. pdf).

[2]One younger adult did not report their age

SteamVR Home is a highly customizable environment in which players can build their own virtual room (https://store.steampowered.com/app/575430/VR_Home/). In the current study, participants navigated a SteamVR Home space customized by the experimenter before the study. This space was a small virtual home in a wooded landscape. An indoor living room featured furniture and shelves containing various objects and toys. An outdoor patio allowed participants to view the surrounding landscape. Participants could pick up, move, throw, and resize objects in the environment, and could also "teleport" to different locations within the room or patio. Instructions were provided by the experimenter on how to accomplish these actions before the timer for the experience started. Participants could also ask for help at any time during this and future experiences.

Vesper Peak was part of a suite of experiences contained within the Lab program (https://store.steampowered.com/app/450390/The_Lab/). Vesper Peak is a mountain site-seeing experience and represents a digital recreation of Vesper Peak in Washington, United States. Participants navigated (through teleportation) to various areas of the mountain range giving them different views. Participants could also interact with a robot dog in the experience (pet, play fetch). Guided Meditation VR is a relaxation and meditation experience (https://store.steampowered.com/app/397750/Guided_Meditation_VR/). Participants experienced the "Nokia Bay" environment, which featured a tropical waterfall. Participants also heard piano music. Participants were asked to look and move (teleport) around the environment while they relaxed and listened to the music.

Xortex is a fast-paced action game experience, also part of The Lab program. In Xortex, the player controls a small spaceship and must maneuver it in a three-dimensional space to destroy increasingly difficult waves of enemy ships while dodging projectiles. If participants lost (their ship was hit by a projectile), the game was restarted. This continued for a total of 3 minutes. Given the fast-paced nature of this game, there were greater concerns about cybersickness, motivating the shorter duration of this experience compared to others.

Of primary interest were measures of presence. After each experience, presence was measured using the IGroup Presence Questionnaire (IPQ) (Schubert, 2003). Subscales of the IPQ include Spatial Presence (5 questions, e.g., Somehow I felt that the virtual world surrounded me), Involvement (4 questions, e.g., I was completely captivated by the virtual world), and Realism (4 questions, e.g., The virtual world seemed more realistic than the real world), along with one general item not belonging to a subscale, General Presence (1 question, i.e., In the computer generated world I had a sense of "being there"). Response options ranged from 1 to 5, and after reverse scoring for negatively framed questions, five represented the highest endorsement of a statement. Responses of subscales with multiple questions were averaged for a single score per subscale.

Workload was also of interest. Would older adults find the experience of VR environments more taxing? To assess this, a modified NASA-TLX (Hart and Staveland, 1988) assessment was administered after the IPQ. To simplify administration, rather than use the original 21-point scale, participants were asked to rate the mental demand, physical demand, temporal demand, their performance, effort, and frustration on a scale of 1 to 7 (higher relating to greater workload). As another measure of usability, at the end of the entire experiment each participant was given the System Usability Scale (SUS) (Brooke, 1996). The SUS is a ten-item scale and asks questions such as "I thought the system was easy to use" and "I felt confident using the system." Scores range from 0 to 100, with higher numbers representing a more positive user experience.

The Simulator Sickness Questionnaire (SSQ) (Kennedy et al., 2009) was used to measure levels of cybersickness. The SSQ was scored as recommended by Bouchard et al. (2014): instead of adding weights to each question as the original SSQ scoring scheme requires, responses were simply summed.

To characterize potential differences in technology proficiency, two measures of proficiency were administered in advance of VR experiences: The Computer Proficiency Questionnaire (CPQ; Boot et al., 2015) and the Mobile Device Proficiency Questionnaire (MDPQ; Roque and Boot, 2018). Both have been demonstrated as reliable and valid measures of technology proficiency among younger and older adults. Finally, to gain additional insight into participants' experiences, after all four VR experiences were completed, participants were asked to type open-ended responses to two questions: 1) What did you enjoy about today's Virtual Reality experiences? and 2) What did you dislike about today's Virtual Reality experiences?

RESULTS

Technology Experience

All supporting data are located on OSF (https://osf.io/vkxde/?view_only=5e36543a3891498da1eeb9a3495698b2). Consistent with previously reported age differences (Boot et al., 2015; Roque and Boot, 2018), older adults were significantly less technology proficient compared to younger adults. Computer Proficiency Questionnaire (CPQ) scores range from 6 to 30, and Mobile Device Proficiency Questionnaire (MDPQ) scores range from 8 to 40, with higher scores representing higher technology proficiency. An ANOVA was conducted on CPQ scores, corresponding to proficiency across a variety of computer tasks. Age (young vs old) and Gender (men vs women) were entered as between-participant factors. This ANOVA indicated that there was a main effect of age [$F(1, 36) = 13.130$, MSE = 69.809, $p < .001$, $\eta_p^2 = .267$][3], no effect of gender [$F(1, 36) = .594$, MSE = 3.160, $p = .446$, $\eta_p^2 = .016$], and no interaction between age and gender [$F(1, 36) = 1.048$, MSE = 1.048, $p = .660$, $\eta_p^2 = .005$]. Younger adults (M = 27.58, SD = 0.85) were more computer proficient compared to older adults (M = 24.90, SD = 3.10). An identical analysis was performed on MDPQ scores, corresponding to technology proficiency across a variety of tasks using smartphones and tablets. There was a main effect of age [$F(1, 36) = 18.264$, MSE = 488.331, $p < .001$, $\eta_p^2 = .337$], no effect of gender [$F(1, 36) = 1.088$, MSE = 27.121. $p = .304$, $\eta_p^2 = 0.029$], and no interaction between age and gender [$F(1, 36) = 0.848$, MSE = 21.139, $p = .363$, $\eta_p^2 = .023$]. Younger adults (M = 31.78, SD = 0.41) were more mobile device proficient compared to older adults (M = 24.90, SD = 7.06).

Measures of Virtual Reality Presence

A Repeated Measures ANOVA was conducted on IPQ General Presence data, corresponding to the overall subjective sense of being present in the virtual environment (Schubert, 2003). Age (young vs old) and Gender (men vs women) were entered as between-participant factors and Experience (Meditation, SteamVR Home, Vesper Peak, Xortex) was entered as a within-participant factor. Here, and elsewhere, violations of sphericity were addressed using Greenhouse–Geisser degrees of freedom and MSE. This analysis indicated a main effect of experience [$F(2.145, 77.217) = 4.981$, MSE = 3.767, $p < .05$, $\eta_p^2 = .122$] and a main effect of age [$F(1, 36) = 5.824$, MSE = 9.290, $p < 0.05$, $\eta_p^2 = .139$]. No other effects or interactions were significant. As can be seen from **Figure 1A**, older adults reported higher levels of general presence compared to younger adults. No a priori hypotheses were made regarding differences between experiences. However, post-hoc t-tests with Bonferroni correction revealed that presence scores were higher for the Vesper Peak experience compared to Meditation ($p < .001$) and Xortex ($p < .05$).

Spatial Presence data, corresponding to the sense of being physically present in a virtual environment (Schubert, 2003), were entered into an identical ANOVA. The analysis revealed a main effect of experience [$F(2.396, 86.273) = 10.289$, MSE = 3.169, $p < 0.001$, $\eta_p^2 = .222$] and a main effect of age [$F(1, 36) = 4.883$, MSE = 4.883, $p < 0.05$, $\eta_p^2 = .120$]. Here again, older adults reported higher presence scores compared to younger adults (**Figure 1B**). Post-hoc t-tests with Bonferroni correction revealed that Meditation was rated as significantly lower in terms of spatial presence compared to all other experiences (all p values <0.05).

Next, we ran the exact same analysis on IPQ Involvement Data, with involvement being defined as the attention one gives to the virtual environment and how involved one is with the experience (Schubert, 2003). This analysis revealed a main effect of experience [$F(4.425, 78.355) = 9.260$, MSE = 4.425, $p < 0.001$, $\eta_p^2 = .205$] and a main effect of age [$F(1, 36) = 6.214$, MSE = 11.926, $p < 0.05$, $\eta_p^2 = .147$]. In general, older adults reported a greater level of involvement compared to younger adults (**Figure 1C**). Post-hoc t-tests with Bonferroni correction revealed that scores were higher for the Xortex experience compared to Meditation ($p < .01$) and SteamVR Home ($p < .01$). Vesper Peak was also rated higher than Steam Home VR ($p < .05$).

Finally, the same analysis was conducted on IPQ Realism data, with realism being defined as the subjective experience of realism of the virtual environment (Schubert, 2003). This analysis indicated a main effect of experience [$F(2.168, 78.037) = 13.253$, MSE = 7.063, $p < 0.001$, $\eta_p^2 = .269$] and a main effect of age [$F(1, 36) = 5.096$, MSE = 7.183, $p < 0.05$, $\eta_p^2 = .124$]. As can be seen from **Figure 1D**, older adults reported higher levels of realism. Vesper Peak was reported as more realistic than Meditation ($p < .001$) and SteamVR Home ($p < .001$). Xortex

[3]Effect sizes are reported as partial eta-squared (η_p^2). Cohen (1969) recommendation for interpretation are ~0.01 for small, 0.06 for medium, and 0.14 for large effects

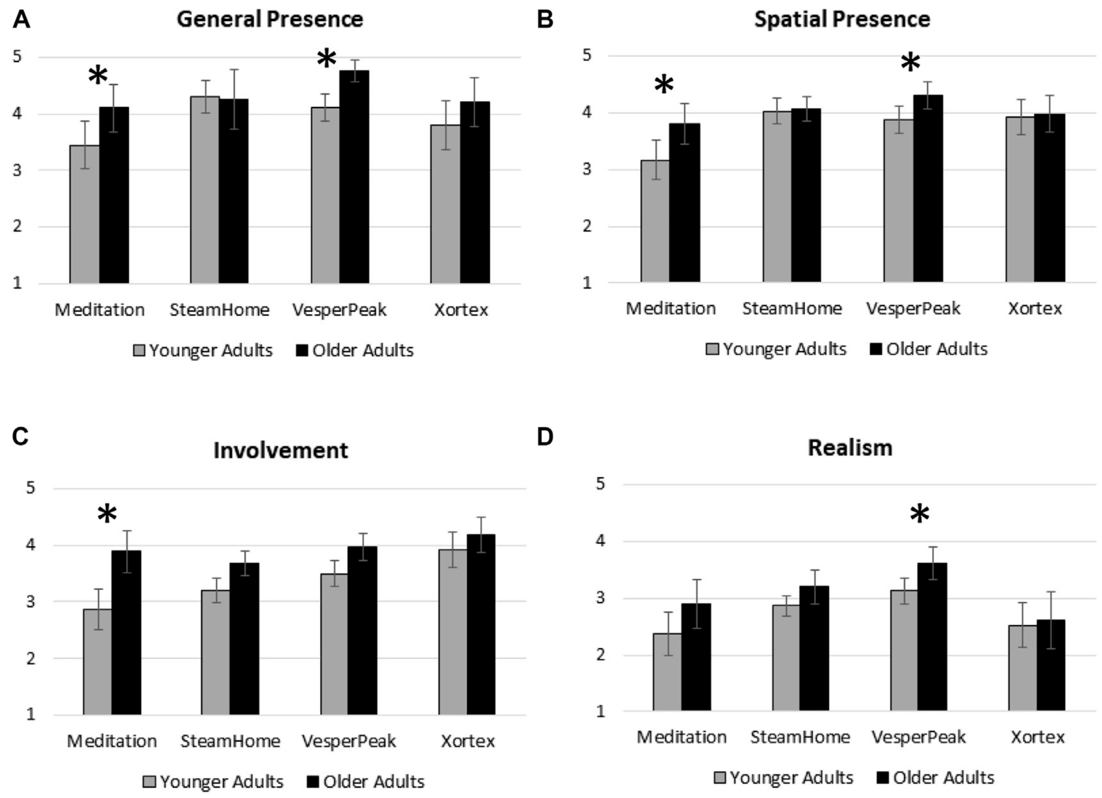

FIGURE 1 | Measures of Presence, Involvement, and Realism as a function of age and VR Experience. Error bars represent 95% Confidence Intervals. * = significant age contrasts, $p < .05$. N = 20 younger adults, 20 older adults.

was among the least realistic, rated significantly lower compared to Vesper Peak ($p < .001$) and SteamVR Home ($p < .05$). Finally, Steam Home VR was reported as being more realistic than Meditation ($p < .05$).

In summary, in general, older adults reported higher levels of presence within VR environments across multiple measures of presence compared to younger adults (see **Figure 2** for scatterplots of these relationships, largely consistent with ANOVA results). Not surprisingly, given the diversity of the experiences participants were asked to interact with, measures of presence varied across experiences. Intuitively, the most photo-realistic experience (Vesper Peak) was rated high in terms of presence, and the most dynamic and game-like experience (Xortex) was rated high in terms of involvement, but low in terms of realism.

Measures of Workload

An identical analysis was conducted on NASA TLX Mental Demand data (**Figure 3A**). This revealed a main effect of age [$F(1, 36) = 6.98$, MSE = 33.337, $p < 0.05$, $\eta_p^2 = .162$], a main effect of experience [$F(2.150, 77.400) = 15.463$, MSE = 39.032, $p < 0.001$, $\eta_p^2 = .300$], and an interaction between age and experience [$F(2.150, 77.400) = 4.827$, MSE = 12.185, $p < 0.01$, $\eta_p^2 = .118$]. To probe the nature of this interaction post-hoc ANOVAs were conducted on each experience separately using age as the between-participant factor. This revealed a main effect of age in the SteamVR Home experience exclusively [$F(1, 38) = 32.510$, MSE = 55.225, $p < .001$, $\eta_p^2 = .461$]. Older adults reported higher mental workload compared to younger adults for this experience. With respect to experience, post-hoc t-tests with Bonferroni correction revealed that Xortex was more demanding than Vesper Peak ($p < .01$) and Meditation ($p < .001$). Meditation was rated as less demanding compared to SteamVR Home ($p < .01$) and Vesper Peak ($p < .05$).

For the NASA TLX Physical Demand data (**Figure 3B**), there was a significant main effect of experience only ($F(1.836, 66.086) = 16.102$, MSE = 28.994, $p < 0.001$, $\eta_p^2 = .309$). Post-hoc t-tests with Bonferroni correction revealed that Xortex was more physically demanding than all other experiences (all p values <0.01). Vesper Peak was also rated as more physically demanding than Meditation ($p < .01$).

The same analysis was conducted on NASA TLX Temporal Demand data (**Figure 3C**). This analysis revealed a significant main effect of experience only [$F(1.387, 49.923) = 32.296$, MSE = 87.911, $p < 0.001$, $\eta_p^2 = .480$]. Not surprisingly, this appeared to be driven by greater temporal demands associated with the fast-paced action game Xortex. Xortex was rated to have a greater temporal demand compared to all other experiences (all p values <0 .001).

The exact same analysis was conducted on NASA TLX Frustration data (**Figure 3D**). The analysis indicated no significant effects (p values for all main effects and interactions

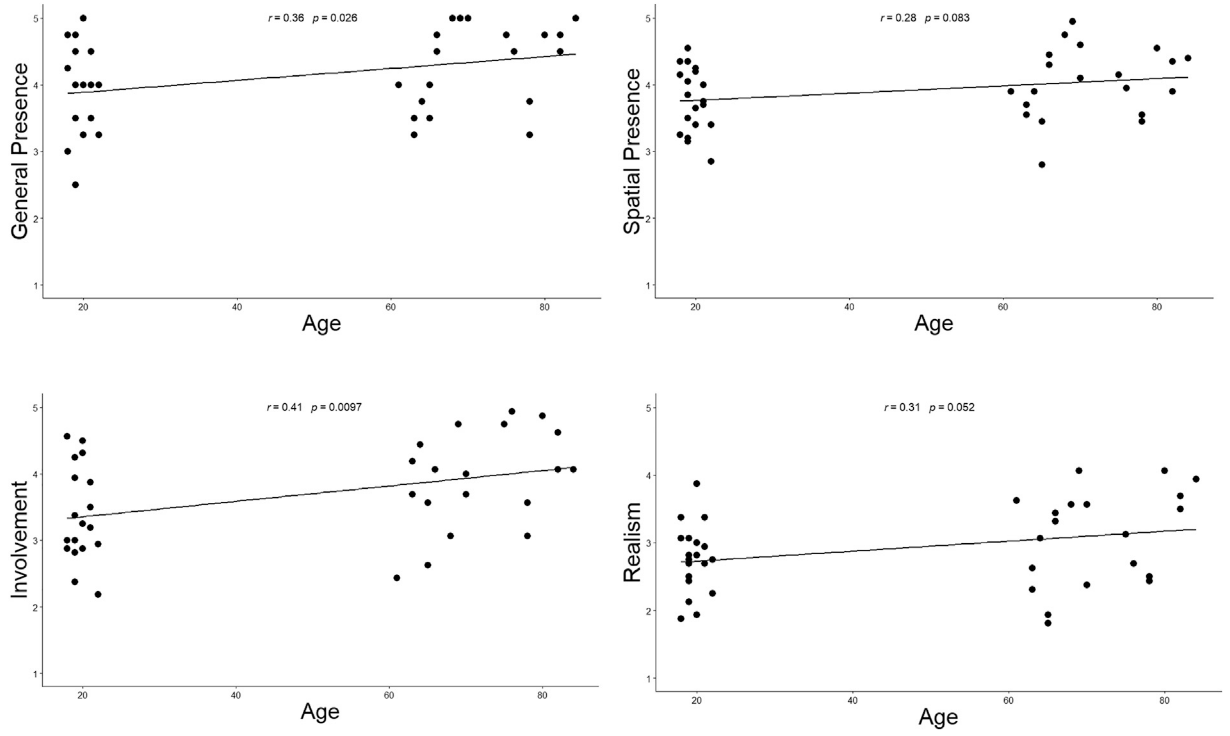

FIGURE 2 | Scatter plot depicting the relationship between presence measures (averaged across experiences) and age. As one younger adult did not report their age, N = 19 younger adults, 20 older adults.

>.21). Older and younger adults did not differ in their feelings of frustration towards the experiences.

Finally, we turn to NASA TLX Effort data (**Figure 4**). This analysis indicated that there was a significant main effect of experience [F(2.178, 78.409) = 31.794, MSE = 77.386, $p < .001$, $\eta_p^2 = .469$] and a significant interaction between gender and age [F(1, 36) = 4.443, MSE = 38.753, $p < 0.05$, $\eta_p^2 = .110$]. To probe the nature of this interaction we conducted post-hoc ANOVAs on each experience separately with gender and age as between-participant factors. This analysis revealed a significant interaction between gender and age in the Vesper Peak experience [F(1, 36) = 6.716, MSE = 24.197, $p < 0.05$, η_p^2 = 157]. That is, among older adults, women reported less effort than men, whereas among younger adults, women reported higher levels of effort than did. Xortex was more effortful compared to all other experiences (all p values <0 .001) and SteamVR Home was more effortful compared to Meditation ($p < .05$), according to post-hoc t-tests with Bonferroni correction.

While in some instances, age differences were evident, for many experiences older adults and younger adults reported similar workload ratings. This was true in general for measures of Temporal Demand and Frustration, and many experiences with respect to Mental Demand and Physical Demand. This was despite clear evidence from the CPQ and MDPQ that older adults were less proficient overall with technology. When differences occurred, older adults tended to report higher levels of demand compared to younger adults, though sometimes age interacted with gender. Not surprisingly, the more complex environments were associated with higher demands compared to experiences like Meditation and Vesper Peak.

Usability

The System Usability Scale (SUS) is a well-validated measure of usability that yields a single usability score from 0 to 100. An ANOVA was conducted on SUS data with Age (young vs old) and Gender (male vs female) as between-participant factors. This analysis revealed no effect of age [F(1, 36) = 1.666, MSE = 216.282 $p = 0.205$, $\eta_p^2 = .044$], no effect of gender [F(1, 36) = 1.836, MSE = 238.413. $p = 0.184$, $\eta_p^2 = .049$], and no interaction [F(1, 36) = 0.072, MSE = 9.356, $p = 0.790$, $\eta_p^2 = 0.002$]. Older adults reported positive user experiences (M = 73.38, SD = 9.78) similar to younger adults (M = 77.13, SD = 12.81).

Cybersickness

An ANOVA was conducted on SSQ (measuring simulator/ cybersickness) data with Age (young vs old) and Gender (male vs female) as between-participant factors. This analysis revealed a main effect of age [F(1, 36) = 5.554, MSE = 37.411, $p < .05$, η_p^2 = 0.134]. Contrary to expectations, older adults experienced less cybersickness (M = 1.35, SD = 1.60) compared to younger adults (M = 3.50, SD = 3.22), though in general, rates of cybersickness for both groups were low. For the distribution of scores, see **Figure 5**. To address potential issues of skew, the same ANOVA was conducted on log transformed data with similar results [age effect F(1, 36) = 7.778, MSE = .735, $p < .01$, $\eta_p^2 = .178$].

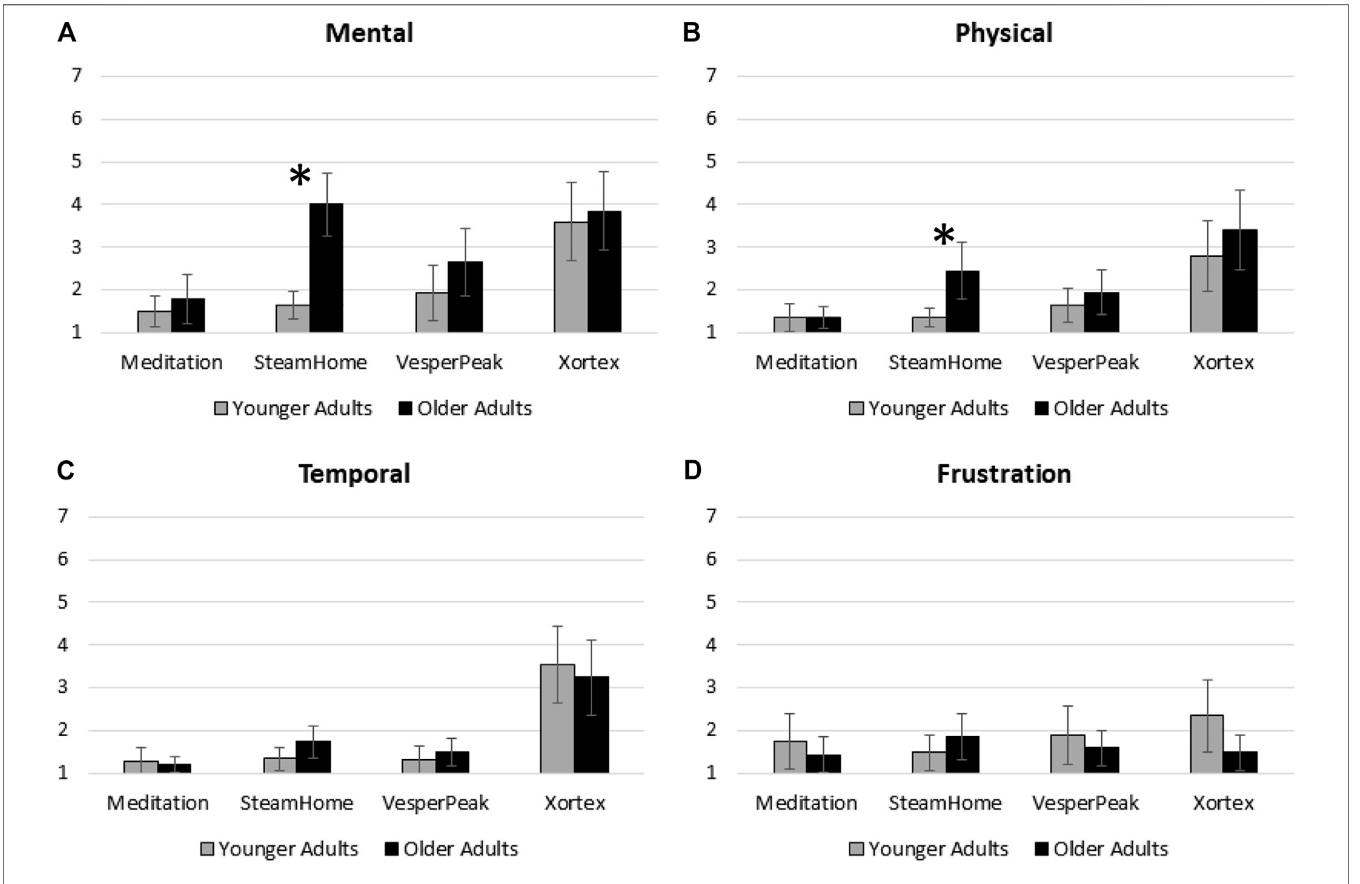

FIGURE 3 | Workload measures as a function of age and VR Experience for measures of mental, physical, and temporal demand, as well as frustration. Error bars represent 95% Confidence Intervals. * = significant age contrasts, $p < .05$. N = 20 younger adults, 20 older adults.

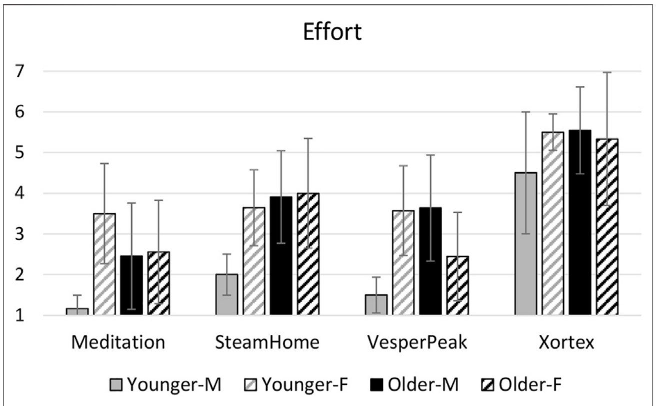

FIGURE 4 | Effort as a function of age, gender, and VR Experience. Error bars represent 95% Confidence Intervals. N = 6 younger males, 14 younger females, 11 older males, 9 older females.

Likes and Dislikes

Participants were asked about their likes and dislikes at the end of the experiment (see OSF for full responses; https://osf.io/vkxde/?view_only=5e36543a3891498da1eeb9a3495698b2). All older adults reported aspects of the experiences that they enjoyed, including being able to do things they could not do in reality and the ability to see new places. Older participants generally reported their experiences were relaxing, enjoyable, and fun. For dislikes, 45% of older adults reported comments that conveyed that there was “nothing” that they disliked about their experiences. Two participants reported comments related to difficulty using the controllers, and one participant reported disliking the cord on the headset (though this was not unique to older adults). Other comments related to wanting to explore and move through the environment more or wanting more time within the virtual environments. In general, comments were strongly positive with no strongly negative comments. Three older adult participants mentioned the fast-paced or challenging nature of Xortex as a dislike. Younger adult comments were similar to those of older adults. Younger participants generally reported fun and enjoyment. For dislikes, one participant reported dislike of the controllers and one reported dissatisfaction with the headset cord. However, a greater number of younger participants (five) reported dislikes related to Meditation VR due to its general lack of interactivity (while only one older adult mentioned this).

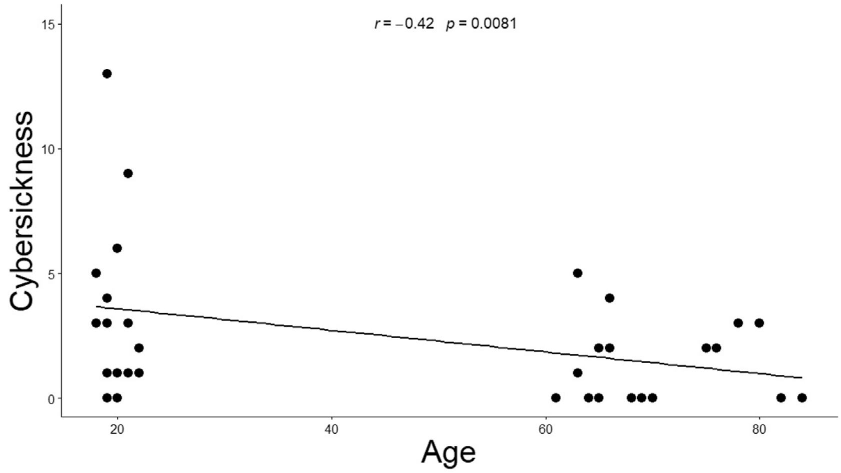

FIGURE 5 | Scatter plot depicting the relationship between cybersickness and age. As one younger adult did not report their age, N = 19 younger adults, 20 older adults.

DISCUSSION

To begin to understand potential barriers to use and adoption of VR technology to support EADL activities among older adults, the current study explored older adults' and younger adults' experiences within VR environments, specifically with respect to their sense of presence, a defining characteristic of VR technology, and issues related to workload and cybersickness.

Older adults were exposed to a diverse set of VR environments, from relatively passive viewing experiences (Meditation VR) to a fast-paced action game (Xortex). These four experiences were chosen to represent a variety of EADL activities. In SteamVR Home, subjects could participate in a variety of household leisure activities. Vesper Peak represented outdoor activities. Meditation VR was used for well-being activities. Finally, Xortex investigated the feasibility of videogame play in VR. Across all presence measures, older adults reported a greater sense of presence in these environments. This greater sense of presence was not associated with greater cybersickness, and there were nonsignificant differences between younger adults in terms of perceived workload, and younger and older adults also rated system usability as high. Workload and usability were perceived similarly though older adults were less proficient overall with technology.

The pattern observed for older adults relative to younger adults of greater presence and less cybersickness is consistent with recent thinking on the relationship between these two factors. Weech et al. (2019) conducted a systematic review and identified 20 papers that measured the relationship between presence and cybersickness. While some papers reported positive correlations and others reported absent correlations, the balance of evidence was in favor of a negative relationship. Weech and colleagues (2019) interpreted this negative relationship as bidirectional: increased presence pulls attention away from sensory conflicts responsible for cybersickness and cybersickness may distract participants and decrease presence. In their empirical investigation of the relations between narrative, gaming experience, presence, and cybersickness, Weech et al. (2020) replicated the expected negative relationship between presence and cybersickness. Our study provides additional evidence for this inverse relationship at the group level—older adults experienced greater presence, but less cybersickness, relative to younger adults.

The current results add to an increasingly positive assessment of the potential of VR to be accepted by older adults and used as an EADL support technology. Positive attitudes in terms of ease of use and usefulness and minimal cybersickness were reported in previous studies (Appel et al., 2020; Huygelier et al., 2019). However, Roberts et al. (2019) noted more mixed reactions to VR experiences by older adults, with both positive and negative emotions being expressed after VR exposure. Negative emotions related to experiences of cybersickness and the cumbersomeness of the headset. It should be noted that the study by Roberts and colleagues utilized a different VR system (Samsung Gear VR headset) compared to our study, different VR experiences ("Jurassic World" and "Cirque du Soleil") and recruited a more diverse sample that could include participants living in nursing homes and assisted living facilities. All of these may be relevant factors in determining perceptions of VR. Similarly, reviews of VR technology suggest that cybersickness could present a significant hurdle to older adult users' adoption (Lee et al., 2019).

Older adults did not experience greater cybersickness compared to younger adults in the current study. Instead, few symptoms of sickness were reported and older adults, on average, reported fewer symptoms of sickness compared to younger adults. What can account for this surprising result? Some studies find that older adults are more prone to sickness while navigating driving simulator scenarios (Brooks et al., 2010; Kawano et al., 2016; Keshavarz et al., 2018). However, unlike driving simulation, the VR experiences participants encountered here involved minimal mismatch between visual and vestibular information. In the case of driving simulation, a participant may have the visual experience of moving at 60 mph, yet the bodily sensation of being stationary. In the VR environments participants navigated here there was generally a 1 to 1 mapping of visual motion to bodily motion. It should also be noted that older VR studies may not present an accurate assessment of cybersickness susceptibility when considering newer, more technologically advanced headsets. Further, as is common in many commercial VR programs, participants were stationary for all VR experiences and navigated using the "teleport" function which allowed for instantaneous movement from one location to another. This may account for low rates of sickness in general, but what might account for older adults' lower sickness compared to younger adults? A hypothesis to explore is that older adults may have been interacting with the VR environments less aggressively and more tentatively, making fewer and slower head and body movements. It is also a possibility that older adult simply experience less cybersickness.

What might account for older adults' greater sense of presence, including involvement and realism? Older adults, on average, have less experience with video games, and generally play different types of video games compared to younger adults (Boot et al., 2020). It is likely that computer generated environments (including environments typical of non-VR games such as first-person shooters) are more familiar to younger adults and more novel to older adults. Novelty may engender a greater sense of presence because the VR experience is more unique for older adults compared to younger adults. Larger studies would be able to explore how individual difference factors, including individual differences in gaming history, might relate to sense of presence, involvement, and realism when interacting with VR environments.

Limitations

Overall, VR appears to be a promising technology for use with older adults, but several limitations of the current study must be acknowledged. While gender differences were explored in reported analyses, it is important to acknowledge the unequal gender distribution of each group, which may have impacted our ability to assess and understand differences between genders and age groups. Likewise, the shortcomings of self-report measures, which may be biased, should be noted. Although many studies utilize self-report measures of simulator sickness (Appel et al., 2020; Narciso, 2019; Yildirim, 2020), there may be potential in predicting and gauging cybersickness by analyzing participant-level and application-level predictors (Rebenitsch and Owen, 2019; Kim et al., 2021). Even still, self-report measures of cybersickness, workload, and presence are common and well accepted in the VR literature. The timing of the questionnaires should also be noted, especially the presence questionnaires which were administered after each experience. However, in general, Schwind et al. (2019) reported no impact on mean scores when assessing measures during vs after the VR experience. They note that administering the questionnaire within the VR environment could, however, reduce study duration and disorientation.

Reports of workload and usability were generally comparable between younger and older adults. However, sample size (N = 40) was constrained due to available resources. A post-hoc power analysis, for a sample of 40, indicated that the study was only powered to detect large mean differences between groups (minimum $d = .92$, $\alpha = .05$, $\beta = .80$). Null effects, including the absence of observed age effects on measures of workload and usability, should be interpreted with caution. Small or medium age effects could exist and be revealed in studies featuring larger sample sizes. It is also important to note that workload and usability were measured with respect to a system that was already setup by the experimenter, and with the assistance of an experimenter who provided guidance. In the absence of such guidance, it is likely that both younger and older adults would have had much less positive VR experiences. Older adults, as a result of their less technology experience (Boot et al., 2015), might have experienced greater challenges setting up and using the system and navigating to the appropriate VR program.

Additionally, results reported here reflect experiences after short-term exposure to VR. It is unclear how attitudes and experiences of younger and older adults might change after prolonged use of VR technology. It should also be noted that participants experienced all VR experiences in a fixed order, and perceptions of one experience may have been influenced by ones experienced prior. Larger studies will be able to explore the impact of potential order effects, and future studies should also parametrically manipulate exposure duration to obtain a better sense of how duration impacts all factors discussed here. However, despite these limitations, results provide initial insight into potential age-related differences in the experience of VR and barriers to the use and adoption of VR technology.

CONCLUSION

Current literature suggests that VR holds tremendous promise with respect to its potential for enhancing the general well-being, emotional, psychological, and social health of older adults, as well as facilitating gaming and leisure activities. Results reported here suggest that VR is a feasible technology for older adults and that they may be able to take advantage of this technology and its benefits just as effectively as younger adults.

AUTHOR'S NOTE

Data are located on OSF (https://osf.io/vkxde/?view_only=5e36543a3891498da1eeb9a3495698b2).

DATA AVAILABILITY STATEMENT

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found in the article/supplementary material.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Florida State University Human Subjects Committee. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

AD and WB developed the concept for the reported experiment. AD and RA developed and refined the experimental protocol. AD collected data and AD and WB analyzed this data. AD wrote the first draft of this manuscript, and WB and RA edited the manuscript.

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REFERENCES

Appel, L., Appel, E., Bogler, O., Wiseman, M., Cohen, L., Ein, N., et al. (2020). Older Adults with Cognitive And/or Physical Impairments Can Benefit from Immersive Virtual Reality Experiences: A Feasibility Study. *Front. Med.* 6 (329), 1–13. doi:10.3389/fmed.2019.00329

Boot, W. R., Andringa, R., Harrell, E. R., Dieciuc, M. A., and Roque, N. A. (2020). Older Adults and Video Gaming for Leisure: Lessons from the Center for Research and Education on Aging and Technology Enhancement (CREATE). *Gerontechnology* 19 (2), 138–146. doi:10.4017/gt.2020.19.2.006.00

Boot, W. R., Charness, N., Czaja, S. J., Sharit, J., Rogers, W. A., Fisk, A. D., et al. (2015). Computer Proficiency Questionnaire: Assessing Low and High Computer Proficient Seniors. *The Gerontologist* 55 (3), 404–411. doi:10.1093/geront/gnt117

Bouchard, S., St-Jacques, J., Renaud, P., and Wiederhold, B. K. (2014). Side Effects of Immersions in Virtual Reality for People Suffering from Anxiety Disorders. *J. CyberTherapy Rehabil.* 2 (2), 127–137.

Brooke, J. (1996). SUS-A Quick and Dirty Usability Scale. *Usability Eval. Industry* 189 (194), 4–7. doi:10.1201/9781498710411-35

Brooks, J. O., Goodenough, R. R., Crisler, M. C., Klein, N. D., Alley, R. L., Koon, B. L., et al. (2010). Simulator Sickness during Driving Simulation Studies. *Accid. Anal. Prev.* 42 (3), 788–796. doi:10.1016/j.aap.2009.04.013

Brown, A. (2017). Younger Men Play Video Games, but So Do a Diverse Group of Other Americans. Available at: https://www.pewresearch.org/fact-tank/2017/09/11/younger-men-play-video-games-but-so-do-a-diverse-group-of-other-americans/ (Accessed July 4, 2021).

Charness, N., and Boot, W. R. (2009). Aging and Information Technology Use. *Curr. Dir. Psychol. Sci.* 18 (5), 253–258. doi:10.1111/j.1467-8721.2009.01647.x

Classen, S., Bewernitz, M., and Shechtman, O. (2011). Driving Simulator Sickness: an Evidence-Based Review of the Literature. *Am. J. Occup. Ther.* 65 (2), 179–188. doi:10.5014/ajot.2011.000802

Cohen, J. (1969). *Statistical Power Analysis for the Behavioral Sciences*. New York, NY: Academic Press.

Czaja, S. J., Boot, W. R., Charness, N., and Rogers, W. A. (2019). *Designing for Older Adults. Principles and Creative Human Factors Approaches*. Florida, United States: CRC Press.

De Schutter, B., Brown, J. A., and Vanden Abeele, V. (2015). The Domestication of Digital Games in the Lives of Older Adults. *New Media Soc.* 17 (7), 1170–1186. doi:10.1177/1461444814522945

Diersch, N., and Wolbers, T. (2019). The Potential of Virtual Reality for Spatial Navigation Research across the Adult Lifespan. *J. Exp. Biol.* 222 (Suppl. l_1), jeb187252. doi:10.1242/jeb.187252

Harrington, C. N., Hare, K. J., and Rogers, W. A. (2017). Developing a Quick-Start Guide to Aid Older Adults in Interacting with Gesture-Based Video Games. *Proc. Hum. Factors Ergon. Soc. Annu. Meet.* 61 (1), 32–36. doi:10.1177/1541931213601503

Hart, S. G., and Staveland, L. E. (1988). Development of NASA-TLX (Task Load Index): Results of Empirical and Theoretical Research. *Adv. Psychol.* 52, 139–183. doi:10.1016/s0166-4115(08)62386-9

Horgas, A., and Abowd, G. (2004). "The Impact of Technology on Living Environments for Older Adults," in *Technology for Adaptive Aging*. Washington, DC: The National Academies Press. Available at: https://www.ncbi.nlm.nih.gov/books/NBK97336/.

Hughes, T. F., Chang, C.-C. H., Vander Bilt, J., and Ganguli, M. (2010). Engagement in reading and Hobbies and Risk of Incident Dementia: the MoVIES Project. *Am. J. Alzheimers Dis. Other Demen.* 25 (5), 432–438. doi:10.1177/1533317510368399

Huygelier, H., Schraepen, B., van Ee, R., Vanden Abeele, V., and Gillebert, C. R. (2019). Acceptance of Immersive Head-Mounted Virtual Reality in Older Adults. *Sci. Rep.* 9 (1), 4519. doi:10.1038/s41598-019-41200-6

Kawano, N., Iwamoto, K., Ebe, K., Aleksic, B., Noda, A., Umegaki, H., et al. (2012). Slower Adaptation to Driving Simulator and Simulator Sickness in Older Adults Aging Clinical and Experimental Research. *Aging Clin. Exp. Res.* 24 (3), 285–289. doi:10.1007/bf03325260

Kennedy, R. S., Lane, N. E., Berbaum, K. S., and Lilienthal, M. G. (1993). Simulator Sickness Questionnaire: An Enhanced Method for Quantifying Simulator Sickness. *Int. J. Aviation Psychol.* 3, 203–220. doi:10.1207/s15327108ijap0303_3

Keshavarz, B., Ramkhalawansingh, R., Haycock, B., Shahab, S., and Campos, J. L. (2018). Comparing Simulator Sickness in Younger and Older Adults during Simulated Driving under Different Multisensory Conditions. *Transportation Res. F: Traffic Psychol. Behav.* 54, 47–62. doi:10.1016/j.trf.2018.01.007

Kim, H., Kim, D. J., Chung, W. H., Park, K.-A., Kim, J. D. K., Kim, D., et al. (2021). Clinical Predictors of Cybersickness in Virtual Reality (VR) Among Highly Stressed People. *Sci. Rep.* 11 (1), 1–11. doi:10.1038/s41598-021-91573-w

Kuykendall, L., Tay, L., and Ng, V. (2015). Leisure Engagement and Subjective Well-Being: A Meta-Analysis. *Psychol. Bull.* 141 (2), 364–403. doi:10.1037/a0038508

Lee, L. N., Kim, M. J., and Hwang, W. J. (2019). Potential of Augmented Reality and Virtual Reality Technologies to Promote Wellbeing in Older Adults. *Appl. Sci.* 9 (17), 3556. doi:10.3390/app9173556

Matas, N. A., Nettelbeck, T., and Burns, N. R. (2015). Dropout during a Driving Simulator Study: A Survival Analysis. *J. Saf. Res.* 55, 159–169. doi:10.1016/j.jsr.2015.08.004

Menec, V. H. (2003). The Relation between Everyday Activities and Successful Aging: A 6-year Longitudinal Study. *Journals Gerontol. Ser. B: Psychol. Sci. Soc. Sci.* 58 (2), S74–S82. doi:10.1093/geronb/58.2.s74

Narciso, D., Bessa, M., Melo, M., Coelho, A., and Vasconcelos-Raposo, J. (2019). Immersive 360° Video User Experience: Impact of Different Variables in the Sense of Presence and Cybersickness. *Univ. Access Inf. Soc.* 18, 77–87. doi:10.1007/s10209-017-0581-5

Park, G. D., Allen, R. W., Fiorentino, D., Rosenthal, T. J., and Cook, M. L. (2006). "Simulator Sickness Scores According to Symptom Susceptibility, Age, and Gender for an Older Driver Assessment Study," in Proceedings of the human factors and ergonomics society annual meeting (Los Angeles, CA: Sage CASAGE Publications). 50 No. 26, 2702–2706. doi:10.1177/154193120605002607

Ramprasad, C., Tamariz, L., Garcia-Barcena, J., Nemeth, Z., and Palacio, A. (2019). The Use of Tablet Technology by Older Adults in Health Care Settings-Is it Effective and Satisfying? A Systematic Review and Meta Analysis. *Clin. Gerontologist* 42 (1), 17–26. doi:10.1080/07317115.2017.1322162

Rebenitsch, L., and Owen, C. (2021). Estimating Cybersickness from Virtual Reality Applications. *Virtual Reality* 25 (1), 165–174. doi:10.1007/s10055-020-00446-6

Roberts, A. R., De Schutter, B., Franks, K., and Radina, M. E. (2019). Older Adults' Experiences with Audiovisual Virtual Reality: Perceived Usefulness and Other Factors Influencing Technology Acceptance. *Clin. Gerontologist* 42 (1), 27–33. doi:10.1080/07317115.2018.1442380

Rogers, W. A., Meyer, B., Walker, N., and Fisk, A. D. (1998). Functional Limitations to Daily Living Tasks in the Aged: a Focus Group Analysis. *Hum. Factors* 40 (1), 111–125. doi:10.1518/001872098779480613

Roque, N. A., and Boot, W. R. (2018). A New Tool for Assessing mobile Device Proficiency in Older Adults: The Mobile Device Proficiency Questionnaire. *J. Appl. Gerontol.* 37, 131–156. doi:10.1177/0733464816642582

Saredakis, D., Szpak, A., Birckhead, B., Keage, H. A. D., Rizzo, A., and Loetscher, T. (2020). Factors Associated with Virtual Reality Sickness in Head-Mounted Displays: a Systematic Review and Meta-Analysis. *Front. Hum. Neurosci.* 14, 96. doi:10.3389/fnhum.2020.00096

Schubert, T. W. (2003). The Sense of Presence in Virtual Environments:. *Z. für Medienpsychologie* 15 (2), 69–71. doi:10.1026//1617-6383.15.2.69

Schwind, V., Knierim, P., Haas, N., and Henze, N. (2019). Using Presence Questionnaires in Virtual Reality. *CHI '19: Proc. 2019 CHI Conf. Hum. Factors Comput. Syst.* 360, 1–12. doi:10.1145/3290605.3300590

Seifert, A., and Schlomann, A. (2021). The Use of Virtual and Augmented Reality by Older Adults: Potentials and Challenges. *Front. Virtual Reality* 2, 51. doi:10.3389/frvir.2021.639718

Weech, S., Kenny, S., and Barnett-Cowan, M. (2019). Presence and Cybersickness in Virtual Reality Are Negatively Related: A Review. *Front. Psychol.* 10, 158. doi:10.3389/fpsyg.2019.00158

Weech, S., Kenny, S., Lenizky, M., and Barnett-Cowan, M. (2020). Narrative and Gaming Experience Interact to Affect Presence and Cybersickness in Virtual Reality. *Int. J. Human-Computer Stud.* 138, 102398. doi:10.1016/j.ijhcs.2020.102398

Winter, C., Kern, F., Gall, D., Latoschik, M. E., Pauli, P., and Käthner, I. (2021). Immersive Virtual Reality during Gait Rehabilitation Increases Walking Speed and Motivation: a Usability Evaluation with Healthy Participants and Patients with Multiple Sclerosis and Stroke. *J. NeuroEngineering Rehabil. (Jner)* 18 (1), 1–14. doi:10.1186/s12984-021-00848-w

Yen, H.-Y., and Chiu, H.-L. (2021). Virtual Reality Exergames for Improving Older Adults' Cognition and Depression: A Systematic Review and Meta-Analysis of Randomized Control Trials. *J. Am. Med. Directors Assoc.* 22 (5), 995–1002. doi:10.1016/j.jamda.2021.03.009

Yildirim, C. (2020). Don't Make Me Sick: Investigating the Incidence of Cybersickness in Commercial Virtual Reality Headsets. *Virtual Reality* 24, 231–239. doi:10.1007/s10055-019-00401-0

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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