Cybersickness Abatement from Repeated Exposure to VR with Reduced Discomfort

Taylor A. Doty, Jonathan W. Kelly, Stephen B. Gilbert, and Michael C. Dorneich

Abstract—Cybersickness, or sickness induced by virtual reality (VR), negatively impacts the enjoyment and adoption of the technology. One method that has been used to reduce sickness is repeated exposure to VR, herein Cybersickness Abatement from Repeated Exposure (CARE). However, high sickness levels during repeated exposure may discourage some users from returning. Field of view (FOV) restriction reduces cybersickness by minimizing visual motion in the periphery, but also negatively affects the user's visual experience. This study explored whether CARE that occurs with FOV restriction generalizes to a full FOV experience. Participants played a VR game for up to 20 minutes. Those in the Repeated Exposure Condition played the same VR game on four separate days, experiencing FOV restriction during the first three days and no FOV restriction on the fourth day. Results indicated significant CARE with FOV restriction (Days 1-3). Further, cybersickness on Day 4, without FOV restriction, was significantly lower than that of participants in the Single Exposure Condition, who experienced the game without FOV restriction only on one day. The current findings show that significant CARE can occur while experiencing minimal cybersickness. Results are considered in the context of multiple theoretical explanations for CARE, including sensory rearrangement, adaptation, habituation, and postural control.

Index Terms—Virtual Reality, Cybersickness, Repeated Exposure, Field of View Restriction, Adaptation, Habituation.

1 Introduction

Virtual reality (VR) has found a foothold in many aspects of everyday life [1]. The uptake of VR has been most visible in gaming and entertainment [2], but VR is also being used successfully in other domains such as education, job training, exposure therapy, cognitive and behavioral skill training, and physical rehabilitation [3], [4], [5], [6]. However, cybersickness can present a significant barrier to the effectiveness of VR [1]. Cybersickness, or motion sickness caused by VR, includes symptoms such as nausea, disorientation, and oculomotor discomfort (e.g., eye strain and headache) caused by exposure to VR [7]. Previous research has indicated that about 70% of VR users will experience at least one symptom of cybersickness within 10 minutes of exposure [6], [8].

Researchers have developed numerous methods to mitigate cybersickness (see [9], for a review of several methods). For example, blocking the visual periphery during self-motion, herein referred to as field of view (FOV) restriction (also known as blinders, vignettes, or tunneling), reduces cybersickness [10], [11], [12]. Other work has found that repeated exposure to VR reduces cybersickness [1], [13], [14], herein referred to as Cybersickness Abatement from Repeated Exposure (CARE). However, current cybersickness mitigation tools are imperfect. FOV restriction diminishes the user's visual experience, and CARE involves initial discomfort over multiple exposures. In an ideal scenario, CARE would occur while using a mitigation tool that keeps cybersickness low. Furthermore, CARE should ideally persist when the mitigation tool is removed. Under this ideal scenario, the user could eventually be exposed to the full visual experience of VR with minimal cybersickness during and after the CARE period. However, prior work has not combined CARE with cybersickness mitigation tools. Therefore, the current study evaluated CARE while providing FOV restriction and whether CARE with FOV restriction generalizes to a full FOV experience. If CARE occurs while using FOV restriction, a user could obtain the benefits of CARE while minimizing discomfort during initial exposure.

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2 Background

2.1 Repeated Exposures to Cybersickness

The experience of motion sickness can be reduced through repeated exposure to the same motion (e.g., boats, cars), which reflects a desensitization to the motion stimulus [15]. Programs focusing on reduced susceptibility to motion stimuli through repeated exposures have prepared fighter pilots, astronauts, and sailors for the physical motion experienced in their work [16]. Similarly, diminished cybersickness levels can occur through repeated exposure to VR [1], [13], [14], [17], [18], [19], [20], [21], [22]. For example, a 15-minute exposure to the same VR application on two separate days has been shown to produce a 35-40% reduction in cybersickness on the second day [14], [21], with a continued reduction over several subsequent exposures [20]. Previous video game and

VR experience, such as those that are considered "gamers," are correlated with lower levels of cybersickness as a form of informal CARE [14], [23], [24].

Ideally, CARE in one context should generalize to another context (e.g., another virtual environment). Otherwise, CARE will need to occur again in each new context. However, research on the generalization of CARE has produced mixed conclusions. A recent study [14] explored whether CARE generalizes across distinct experiences. On the first day of a two-day study, all participants experienced a 15-minute rollercoaster in VR. Half of the participants then experienced a climbing game for 15 minutes on the same day. The other half of the participants did nothing after the rollercoaster. On the second day, all participants again experienced the rollercoaster. Both groups had lower cybersickness levels on the second day of the rollercoaster compared to the first, demonstrating CARE. However, the added climbing experience on the first day did not lead to further reductions in cybersickness compared to the group who did not climb. The authors suggest that CARE that may have occurred during climbing did not generalize to the rollercoaster experience on the second day due to the vastly different locomotion styles each experience requires.

Another study [1] first presented participants with a rich and realistic virtual environment to obtain a baseline measure of cybersickness. Then, participants were exposed to an abstract and less detailed virtual environment over three days while optic flow (i.e., visual motion) was gradually increased. Sickness levels decreased during these three days, indicating CARE. Additionally, reduced levels of cybersickness were maintained when participants returned to the realistic visual environment for a second time. However, the study design left open the possibility that similar levels of CARE would have occurred if participants were exposed to only the realistic environment twice.

In summary, early evidence is mixed as to whether CARE generalizes to different experiences in VR. One study reports that CARE generalizes to another virtual environment [1], and another study reports that CARE does not generalize [14]. The difference in conclusions may lie in defining the changes during the generalization phase (e.g., the environment, interface, task, etc.). Furthermore, both conclusions from these studies may be valid and coexist if they reflect distinct mechanisms leading to cybersickness reductions. Previous work has indicated that several factors about the VR experience can drive cybersickness levels, including but not limited to optic flow [12], [25], the type of locomotion [26], [27], [28], and the amount of interactivity available [21]. However, more research is necessary to determine which factors can limit the generalization of CARE.

2.2 Mitigating Cybersickness with Field of View Restriction

One promising method to reduce cybersickness is by reducing the field of view (FOV) while moving in VR [7], [11], [12], [13], [22], [24], [29], [30], [31]. FOV restriction has been presented in a variety of ways, including dynamic FOV reduction based on movement speed [30], reduction of only the horizontal FOV [12], and blurring of the periphery rather than complete removal [7]. By reducing peripheral vision while the user moves, FOV restriction decreases vection, the illusion of self-motion, and the severity of cybersickness [23], [30], [31]. However, FOV restriction can also reduce awareness of peripheral objects [5], reduce presence [32], [33], and detract from the visual experience [34].

One study [30] included two VR exposures in the same virtual environment, once with and once without FOV restriction, counterbalanced for order. When participants experienced VR without FOV restriction, cybersickness was significantly lower if they had previously experienced VR with FOV restriction (compared to no prior experience). This finding suggests that CARE may have occurred during the session with FOV restriction, and that it generalized to the subsequent experience without FOV restriction. However, it is difficult to determine if CARE occurred because the same condition was never repeated. Further, the sample size (n = 12) was small, making it difficult to draw firm conclusions.

3 Experiment Overview and Hypotheses

Prior work has demonstrated that both FOV restriction and repeated exposure reduce cybersickness individually. However, both techniques have drawbacks (diminished user experience in the case of FOV restriction and initial sickness in the case of repeated exposure). Therefore, the current study evaluated whether CARE occurs while using FOV restriction and whether CARE that occurs with FOV restriction will persist when FOV restriction is removed. Ideally, a user could have reduced cybersickness levels with minimal discomfort during repeated exposures and later comfortably use VR with a full FOV. To test this possibility, participants in a Repeated Exposure Condition experienced four VR sessions on separate days. FOV restriction was enabled on the first three days, and no FOV restriction was used on the fourth day. Participants in a Single Exposure Condition experienced no FOV restriction during their single VR session. The primary hypotheses were:

1) Cybersickness experienced when using FOV restriction would be reduced across repeated exposures (i.e., Days 1-3), and
2) Individuals who repeatedly experienced VR with FOV restriction would subsequently have lower levels of cybersickness when exposed to full FOV VR (i.e., Day 4), compared to individuals without the repeated VR experience.

4 Methods

4.1 Participants

Over four months, 125 students were recruited from Iowa State University. Of these participants, 69 were assigned to the Single Exposure Condition. The remaining 56 participants were assigned to the Repeated Exposure Condition. However, only 34 participants completed all four days. The 22 incomplete participants, citing scheduling conflicts as the primary reason for discontinuing the study, were dropped from data analyses. Section 5.1 compares demographic information and cybersickness measures recorded during Day

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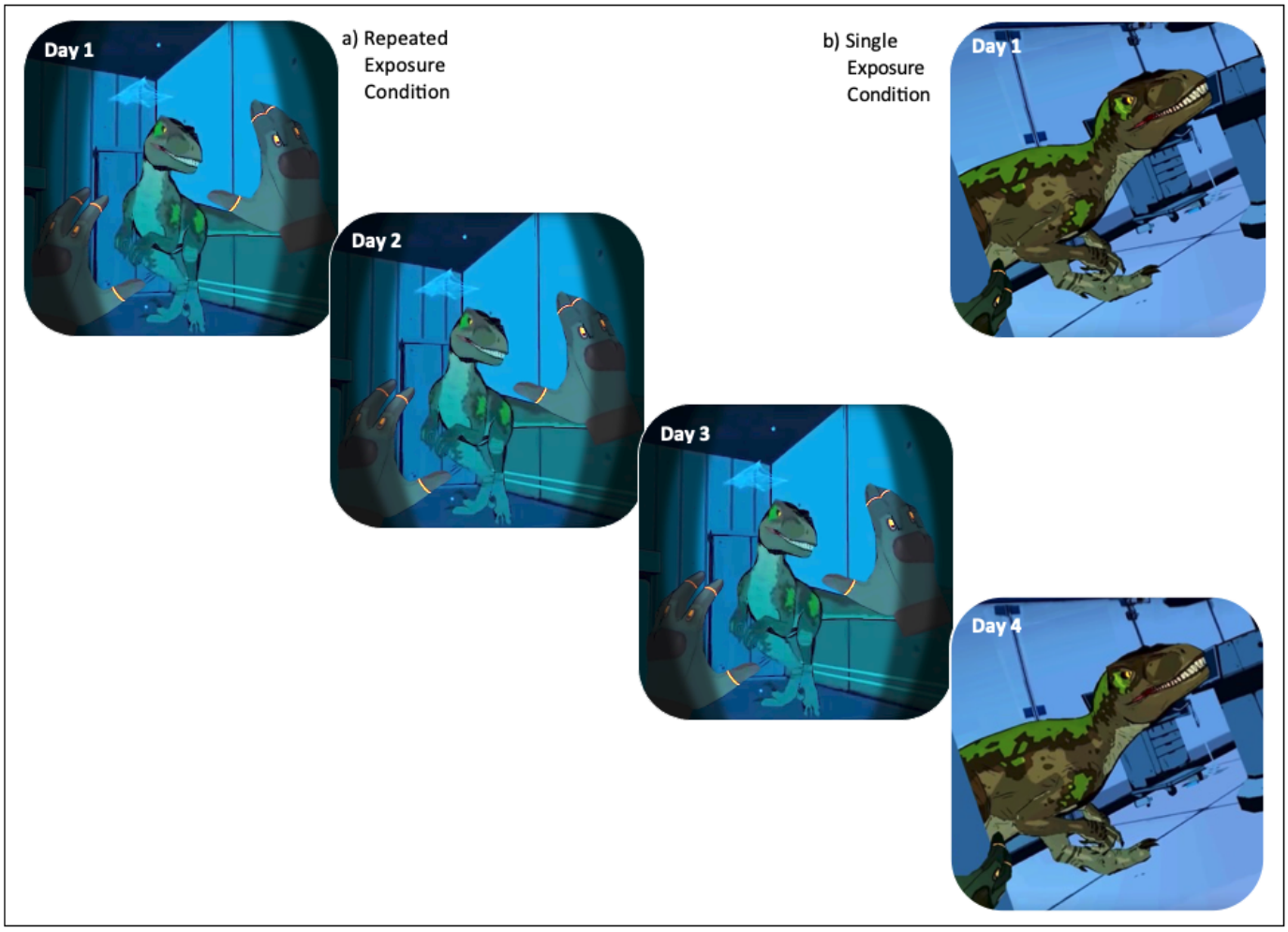


Fig. 1. a) Repeated Exposure Condition Days 1-3 with FOV restriction playing Chapter 1 and Day 4 without FOV restriction playing Chapter 2. b) Single Exposure Condition without FOV restriction playing Chapter 2.

TABLE 1
Demographics of repeated exposure and single exposure groups.

	Repeated Exposure Group n = 34	Single Exposure Group n = 69	Total n = 103
Gender*	20 Male (*58.8%*)	39 Male (*56.5%*)	59 Male (*57.3%*)
Age†	19.2 (*1.4*)	19.0 (*2.1*)	19.0 (*1.9*)
VIMSSQ†	4.2 (*2.7*)	3.9 (*2.6*)	4.0 (*2.6*)
MSSQ†	37.34 (*33.98*)	28.24 (*23.06*)	31.27 (*27.36*)
VR Exp*	8 (*23.5%*)	9 (*13.0%*)	17 (*16.5%*)
VG Exp*	31 (*91.2%*)	67 (*97.1%*)	98 (*95.2%*)
VG Hrs/Wk†	23.8 (*23.2*)	22.0 (*25.1*)	22.6 (*24.4*)
IPD†	62.6 (*3.7*)	61.0 (*3.7*)	61.5 (*3.8*)

*N (%); †Mean (*SD*)

1 of those who completed all four days and those who did not.

Demographic information is displayed in Table 1. The age range of the remaining 103 participants was 18 to 34 (M= 19.0, SD= 1.9) and consisted of 59 males (57.3%). While few participants had previous VR experience (16.5%), most had experience with video games (95.2%), with a range from 0 to 130 hours per average week (M= 22.6, SD= 24.4). A breakdown of types of video games played by self-defined gamers can be found on the Open Science Framework [35]. The short form Motion Sickness Susceptibility Questionnaire (MSSQ) [36] indicated that this sample's susceptibility to motion sickness was slightly below average (M= 31.27, SD= 27.36) [37]. A slightly lower motion sickness susceptibility in this population could exist for a number of different reasons. The most likely, anecdotally, is participant self-selection based on the study listing, which explained that participants were to evaluate VR games. Those that are more likely to play video games are usually less susceptible to motion sickness [14], [23], [24]. Additionally, the short form Visually Induced Motion Sickness Questionnaire (VIMSSQ-short) [38], [39] showed that participants had slightly above average visually induced motion sickness susceptibility (M= 4.0, SD= 2.6) [38], [39]. However, this is likely due to the current sample's younger average age (M= 19.0, SD= 1.9) than previous work (M= 22.9, SD= 5.0) [39]. Another possible reason is the proportion of males to females in the current study (57.3%) compared to previous work (33.3%) [39]. Susceptibility to visually induced motion sickness has been noted to decrease with age and is more prevalent in females than males [39]. Interpupillary distance (IPD)

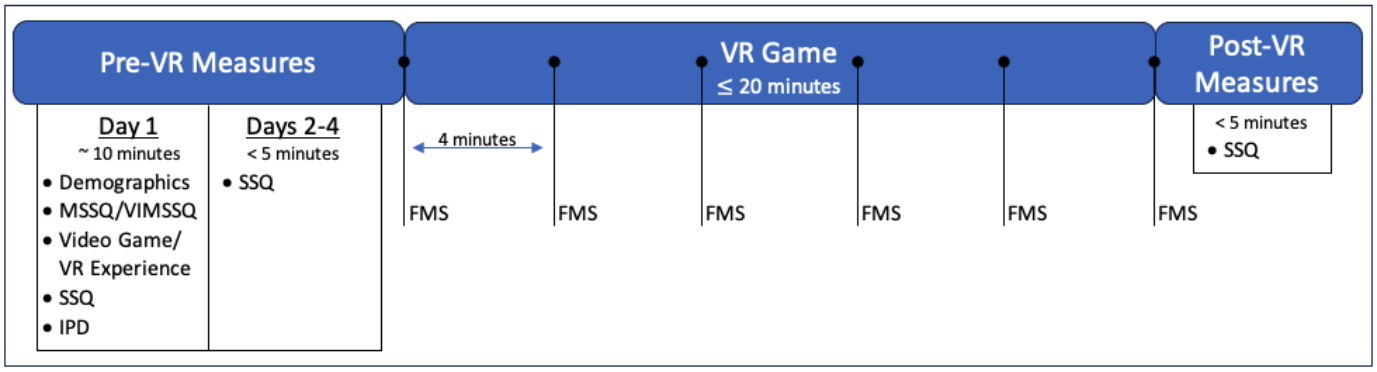


Fig. 2. Timeline of daily procedure for both conditions. Day 1 includes the first day of the Repeated Exposure Condition and the only day of Single Exposure Condition. Days 2-4 shows the remaining days of the Repeated Exposure Condition. Each session lasted no longer than an hour.

ranged from 50 mm to 72 mm (M= 61.5 mm SD= 3.8).

4.2 Experimental Design

There were two conditions in the current study: Repeated Exposure and Single Exposure (see Figure 1 for an overview of the experimental design). Participants in the Repeated Exposure Condition came to the lab a total of four times. Each session after Day 1 was held the following day, between 16 and 32 hours after the previous session, for an average of 24 hours and 22 minutes between sessions. Participants fully recovered between sessions; analyses are shown in 5.3.1. Previous work by Howarth and Hodder (2008) has indicated that the time between exposures is less important than the number of exposures. One condition in their study had participants experience 20 minutes of VR daily over ten consecutive days and found consistent reductions in cybersickness [20]. The present study utilized consecutive days of 20-minute repeated exposures due to the recommendations of prior work [20], ease of data collection, and the improved attendance rates of participants.

On Days 1-3, participants played Chapter 1 of Jurassic World: Aftermath with FOV restriction. FOV restriction is included in the comfort menu's "comfortable" setting and labeled "vignettes." On Day 4, the participants in the Repeated Exposure Condition played Chapter 2 of Jurassic World: Aftermath without FOV restriction (Figure 1a). Participants in the Single Exposure Condition came to the lab only once and played Chapter 2 of Jurassic World: Aftermath without FOV restriction (Figure 1b). The current work's goals were to determine if CARE and generalization are possible with repeated exposures of restricted FOV compared to a single-exposure experience. A full FOV repeated exposure condition to compare rates and degrees of CARE and generalization is outside the scope of the current work. It should be considered for future studies once repeated exposure with restricted FOV has shown capabilities of CARE and generalization.

4.3 Materials

4.3.1 Measures

A table of independent and dependent variables can be found on the Open Science Framework [35]. General demographic information was collected from participants. Additionally, previous experiences of general motion sickness and visually induced motion sickness were recorded utilizing the MSSQ [36] and the VIMSSQ-short [38], respectively. Video game usage was measured in hours per week playing games, as was prior experience with VR. IPD was recorded using a ruler.

Cybersickness measures included the time that the participant was in VR, self-reported sickness recorded every four minutes via a modified version Fast Motion Sickness Scale (FMS; [40]), and the Simulator Sickness Questionnaire (SSQ; [41]) given prior to and after the VR experience. The original FMS was based on a 21-point scale; however, the current study reduced the range to 0 (none) to 10 (severe) for ease of comprehension. The pre-VR SSQ was used to evaluate whether participants in the Repeated Exposure Condition had any residual symptoms from the prior session, and pre-VR SSQ was also measured for the Single Exposure Condition participants for consistency across conditions. The Average Discomfort Score (ADS) was calculated by following Fernandes & Feiner's (2016) recommendation of combining time spent in the environment and the average FMS score (see 4.5 for more details). This measure allows us to distinguish between participants who end the VR exposure at the same sickness level measured by the FMS but at different times, for example.

4.3.2 Stimuli

All participants played up to 20 minutes of Jurassic World: Aftermath [42] on the Oculus Quest 2. Videos of both Restricted FOV and Full FOV for this game are available on the Open Science Framework [35]. This is a VR cat-and-mouse game where players complete puzzles and hide from dinosaurs to escape an island. Participants in the Repeated Exposure Condition played Chapter 1 on the first three days, followed by Chapter 2 on the fourth day. Participants in the Single Exposure Condition only played Chapter 2. Both chapters were very similar in gameplay and mechanics and included significant translational movement and environmental interaction. The participants did not play a tutorial in either condition. However, both chapters included movement guides presented when the player encountered something novel (e.g., the game showing "press in the right joystick to crouch" when the player reached an area where crouching was necessary).

FOV restriction was only enabled for the first three days in the Repeated Exposure Condition. FOV restriction was implemented when moving translationally, sprinting, and crouching. It caused the peripheral vision to become black with a blurred effect at the transition from central to peripheral vision. It was not active for rotational movement using the right joystick or when the player character stood still, and the participant turned their head. Before FOV restriction was enabled and between activations, the maximum FOV was approximately 104° horizontal by 98° vertical. This maximum FOV was also the constant FOV for Day 4 of the Repeated Exposure Condition and the one day of the Single Exposure Condition. As the participant initiated one of the previously mentioned activation conditions, full FOV restriction was quickly engaged (approximately 100 milliseconds) in the horizontal dimension only, disregarding the amount of movement the participant used on the joystick. Full FOV restriction allowed an unobstructed view of the central 40° of the participant's head direction. A semi-transparent dark band between 40° and 60° horizontally separated the clear central vision from a completely black vignette starting at 60° horizontally. Once the participant ended the activation condition, FOV returned to normal just as quickly as the onset. The use of FOV restriction did not impact vertical FOV.

Participants played this game while seated and navigated using joysticks and smooth turning. Joystick locomotion was the only method of movement available in the game's settings. Smooth turning was chosen over snap turning (where moving the right joystick causes the view of the participant to "snap" to set degree turns) because previous research has indicated that snap turning is associated with lower sickness levels than smooth turning, and the current study is only investigating one cybersickness mitigation technique [9], [28], [43].

4.4 Procedure

Figure 2 provides an overview of the daily procedure for participants in all conditions. When the participant entered the lab on the first day, they completed the consent form and pre-VR measures, including demographics, MSSQ, VIMSSQ-short, Video Game Experience, VR Experience, and IPD. SSQ was recorded daily before starting the VR game. The researcher adjusted the Oculus Quest 2's IPD setting to fit the participant's recorded IPD as closely as possible. The controls were explained to the participant and the first FMS recording was taken once the headset was comfortably on their head. Participants were instructed to play the game until the researcher told them to stop at 20 minutes or they felt too sick to continue. The FMS was administered every four minutes until 20 minutes passed or the participant could no longer play due to feelings of motion sickness, resulting in up to six recordings. If they reported an 8 or higher on the FMS at any point, they were reminded that they could stop at any time. The time the participant terminated the VR game was recorded if they ended early. The participant then completed the post-VR SSQ. Each session lasted between 30 minutes and one hour, depending on the participant's speed of completing surveys and breaks they may have needed.

4.5 Data Analyses

Average Discomfort Score (ADS) is a measure that combines sickness ratings taken during VR exposure with time spent in VR [12], [29], [30]. When a participant ended early, their final FMS rating was used for any remaining measurements. Next, all measurements were averaged together to compute ADS. For example, if a participant ended the VR exposure at 15 minutes, their final FMS rating taken at exit would be applied to the missing recordings at 16 and 20 minutes. Previous research has used the maximum possible sickness score (10 in the current study) instead of the participants' final FMS rating for remaining measures [12], [29], [30], but we prefer to use the final FMS rating because it better reflects the participant's experience since not all participants who ended early terminated at the maximum FMS score. The current data lead to identical conclusions when using either method. Aside from Day 1 FOV Restriction (5.2), the following sections do not report final FMS scores and VR exposure time because ADS is calculated using FMS and accounts for exposure time differences. Separate analyses of final FMS scores and VR exposure time can be found on the Open Science Framework [35].

While SSQ data were collected pre- and post-VR exposure, only the post-VR data were used for primary data analyses. Previous research has debated using difference scores, calculated by subtracting each post-VR item from its pre-VR self, or the scores of post-VR only [44]. The current data yields identical inferential statistical conclusions when using either method. As the original questionnaire used post-exposure scores only [41], this study followed its

TABLE 2
Correlations, means, and standard deviations for demographics and cybersickness measures including gender, VIMSSQ-short, MSSQ, age, average video game hours per week, IPD, time in VR, calculated ADS, and the SSQ total score.

	1.	2.	3.	4.	5.	6.	7.	8.	*M*	*SD*
1. Gender	—								—	—
2. VIMSSQ	**-.27****	—							3.96	2.59
3. MSSQ	**-.3****	**.41*****	—						31.27	27.36
4. Age	-.03	.14	-.08	—					19.04	1.89
5. VG Hrs/Wk	**.41*****	-.11	-.19	.02	—				22.57	24.39
6. IPD	**.26****	-.06	.05	-.01	.05	—			61.51	3.8
7. Time	.11	-.16	**-.23***	.12	.02	.13	—		16.51	4.95
8. ADS	**-.34*****	**.28****	**.31****	**-.22***	-.13	-.16	**-.7*****	—	3.23	2.09
9. SSQ-T	**-.3****	**.28****	**.26****	-.18	-.03	**-.21***	**-.45*****	**-.61*****	49.64	37.4

* p <.05, ** p <.01, *** p <.001

recommendation. The SSQ total and its subscales were also calculated according to the original questionnaire [41].

Correlations between key demographics and cybersickness measures for completed participants Only Day 1 for Repeated Exposure Participants) are displayed in Table 2. Correlations with additional cybersickness measures, including time spent in VR, final FMS, and the SSQ subscales, are available on the Open Science Framework [35].

To assess how FOV restrictions impacted sickness levels, an independent samples one-tail t-test compared Day 1 sickness ratings of the Repeated Exposure Condition to the Single Exposure Condition. A repeated measures MANOVA examined sickness ratings (ADS, SSQ total, and SSQ subscales) across Days 1-3 of the Repeated Exposure Group to assess CARE. An additional repeated measures MANOVA compared ADS at each measurement time across Days 1-3 of the Repeated Exposure Group to determine if rates of sickness changed across days. Sickness ratings on Day 4 of the Repeated Exposure Group were compared to those of the Single Exposure Group using an independent samples one-tail t-test to assess whether CARE with FOV restriction generalized to full-FOV VR. A final repeated measures MANOVA investigated if ADS rates across time points differed from the Single Exposure Group and Day 4 of the Repeated Exposure Group. All statistical analyses began with assumption checks, and violations were noted.

5 Results

5.1 Demographics and Assessment of Attrition Bias

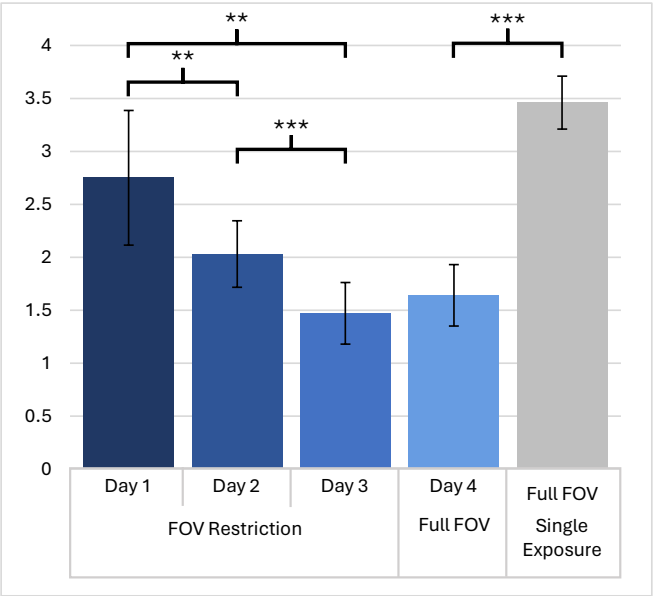
To determine if the 22 participants who did not complete all four days in the Repeated Exposure Condition differed from the 34 participants who did, an independent samples t-test was conducted on key demographics, ADS, SSQ total, and SSQ subscales. These comparisons used only Day 1 data. No significant differences in demographics existed between those who completed all four days and those who did not. Additionally, there were no significant differences in Day 1 cybersickness levels between those who completed four days and those who did not. These analyses and characteristics are available on the Open Science Framework [35].

5.2 Day 1 FOV Restriction

TABLE 3
Comparison between Repeated Exposure Day 1 and Single Exposure Day to evaluate FOV restriction effectiveness. Measures included are final FMS rating, calculated ADS, time in VR, SSQ subscales, and total SSQ.

	Repeated Exposure Restricted FOV Day 1 n = 34	Single Exposure Full FOV n = 69	Sig	Cohen's *d*
FMS	4.37 (*2.97*)	5.62 (*2.93*)	**.022**	0.43 (S)
ADS	2.75 (*2.11*)	3.46 (*2.05*)	.053	0.34 (S)
Time	16.97 (*4.60*)	16.29 (*5.13*)	.258	0.14 (VS)
SSQ-O	33.22 (*23.46*)	33.18 (*26.80*)	.497	0.002 (VS)
SSQ-D	45.04 (*47.86*)	49.63 (*47.65*)	.324	0.96 (L)
SSQ-N	48.26 (*35.07*)	53.65 (*40.21*)	.254	0.14 (VS)
SSQ-T	47.41 (*35.62*)	50.73 (*38.46*)	.337	0.89 (L)

An independent samples one-tail t-test was conducted comparing Day 1 of the Repeated Exposure Condition to the Single Exposure Condition to determine if FOV restriction reduced cybersickness levels compared to a full FOV experience, as shown in Table 3. No measures violated Levene's Test of Equality of Variances; therefore, equal variances were assumed. Those in the Repeated Exposure Condition reported significantly lower final FMS scores (M = 4.37, SD = 2.97) than those in the Single Exposure Condition (M = 5.62, SD = 2.93, $t(101)$ = 2.04, $p < .022$, d = 0.43), and marginally lower ADS (M = 2.75, SD = 2.11) than those in the Single Exposure Condition (M = 3.46, SD = 2.05, $t(101)$ = 1.64, p = .053, d = 0.34), which can be seen in Figure 3. No significant differences were present for exposure time ($t(101)$ = 0.65, p = .258, d = 0.14), SSQ Total ($t(101)$ = 0.42, p = .337, d = 0.89), oculomotor symptoms ($t(101)$ = 0.008, p = .497, d = 0.002), disorientation symptoms ($t(101)$ = 0.46, p = .324, d = 0.96), or nausea symptoms ($t(101)$ = 0.67, p = .254, d = 0.14), as shown in Figure 4. Means and standard deviations are shown in Table 3.



* p <.05, ** p <.01, *** p <.001

Fig. 3. ADS of Days 1-4 of the Repeated Exposure Condition and the Single Exposure Condition.

5.3 Cybersickness Abatement from Repeated Exposures

A repeated measures MANOVA on Days 1-3 of the Repeated Exposure Condition indicated a significant effect of Day, $F(12,122)$ = 3.57, $p < .001$; Wilks's Λ = 0.480, η_p^2 = 0.592. All measures violated sphericity. A Greenhouse-Geisser correction is used. The univariate tests indicated a significant effect of Day for ADS, $F(1.4, 47.3)$ = 14.23, $p < .001$, η_p^2 = 0.301, and SSQ Total, $F(1.5, 49.1)$ = 6.96, p = .005, η_p^2 = 0.174. A further breakdown of the subscales of the SSQ indicated a significant effect of Day for both SSQ-Oculomotor, $F(1.5, 47.9)$ = 4.02, p = .036, η_p^2 = 0.108, and SSQ-Nausea, $F(1.7, 55.8)$ = 14.38, $p < .001$, η_p^2 = 0.304, but not for SSQ-Disorientation, $F(1.6, 51.5)$ = 2.88, p = .078, η_p^2 =

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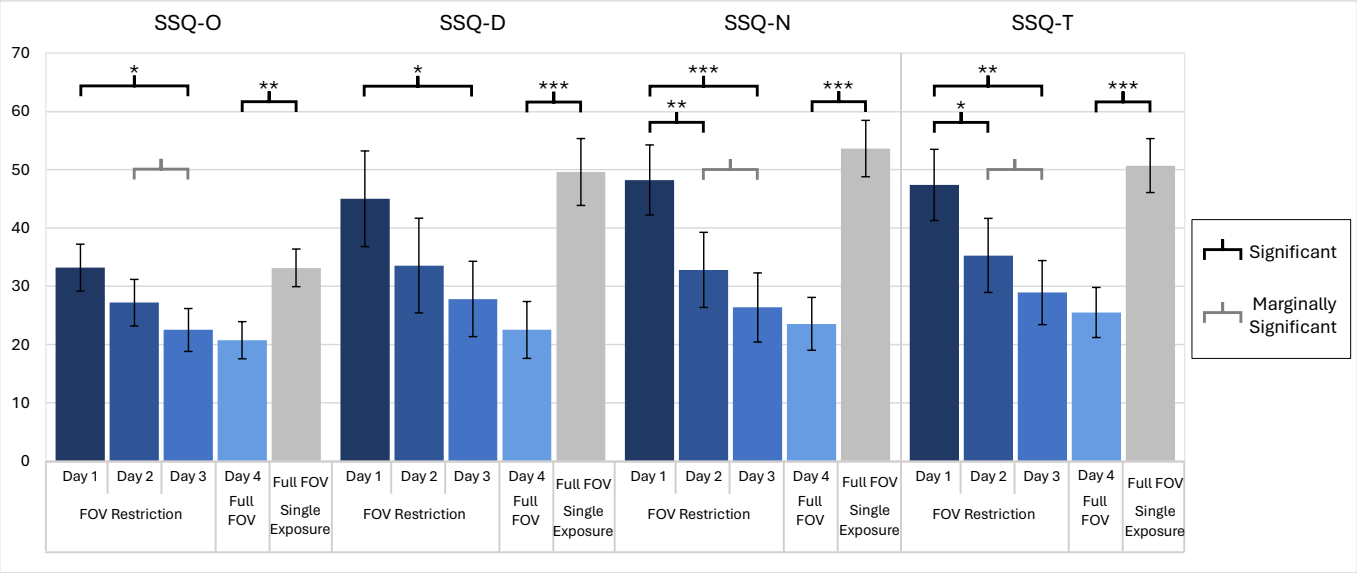

* p <.05, ** p <.01, *** p <.001

Fig. 4. SSQ subscales and total sickness scores of Days 1-4 of the Repeated Exposure Condition and the Single Exposure Condition.

0.080. Means and standard deviations can be found in Table 4. The percentage of participants who change their final FMS across Days 1-3 of the Repeated Exposure Condition can be found on the Open Science Framework [35].

Pairwise comparisons (Table 5) show that ADS was higher on Day 1 than on Day 2 (M_{diff} = 0.72, 95% CI: [0.25, 1.19], p = .004) and Day 3 (M_{diff} = 1.29, 95% CI: [0.67, 1.90], $p < .001$), and that Day 2 ADS was significantly higher than Day 3 (M_{diff} = 0.56, 95% CI: [0.22, 0.91], p = .002), as shown in Figure 3. Total SSQ scores were higher on Day 1 than on Day 2 (M_{diff} = 12.10, 95% CI: [0.63, 23.57], p = .039) and Day 3 (M_{diff} = 18.48, 95% CI: [6.68, 30.28], p =.003), and marginally higher on Day 2 than Day 3 (M_{diff} = 6.38, 95% CI: [-0.22, 12.98], p =.058). Examining the individual SSQ subscales shows that participants on Day 1 reported significantly higher oculomotor symptoms than on Day 3 (M_{diff} = 10.70, 95% CI: [1.54, 19.89], p = .023). No significant difference was found between Days 1 and 2 (M_{diff} = 6.02, 95% CI: [-2.36, 14.40], p = .154), and Day 2 was marginally higher than Day 3 (M_{diff} = 4.68, 95% CI: [-0.19, 9.55], p = .059). Nausea symptoms were significantly higher on Day 1 than on Day 2 (M_{diff} = 15.43, 95% CI: [5.81, 25.06], p = .003) and Day 3 (M_{diff} = 21.89, 95% CI: [12.74, 31.03], $p < .001$), and marginally higher on Day 2 than on Day 3 (M_{diff} = 6.45, 95% CI: [-0.04, 12.94], p = .051). Figure 4 illustrates these differences across Days and Conditions.

An additional repeated measures MANOVA was conducted to assess if changes in discomfort scores across time points were different on Days 1-3. The results of the variable "Day" are identical to those reported above. Results also indicated a significant effect of Time, $F(5,29)$ = 11.20, $p < .001$; Wilks's Λ = 0.341, η_p^2 = 0.659, and a significant interaction of Day and Time, $F(10,24)$ = 3.14, p = .010; Wilks's Λ = 0.433, η_p^2 = 0.567. All measures violated sphericity. Therefore, a Greenhouse-Geisser correction is used for all other measures. The univariate tests indicated a significant effect of Time, $F(1.5, 48.5)$ = 46.45, $p < .001$, η_p^2 = 0.585, and the interaction of Day and Time, $F(4.1, 135.6)$ = 12.05, $p < .001$, η_p^2 = 0.268. Means and standard deviations can be found in Table 6.

Pairwise comparisons (Table 7) further show that there were no significant differences of ADS at minute 0 or 4 between Days 1-3. At minute 8, ADS was significantly higher for Day 1 than Day 2 (M_{diff} = 1.03, 95% CI: [0.41, 1.65], p = .002) and Day 3 (M_{diff} = 1.50, 95% CI: [0.70, 2.30], $p < .001$), and Day 2 was marginally higher than Day 3 (M_{diff} = 0.47, 95% CI: [-0.02, 0.96], p = .059). At minute 12, Day 1 was significantly higher than Day 2 (M_{diff} = 1.07, 95% CI: [0.40, 1.74], p = .003) and Day 3 (M_{diff} = 1.79, 95% CI: [0.95, 2.64], $p < .001$), and Day 2 was significantly higher than Day 3 (M_{diff} = 0.72, 95% CI: [0.25, 1.20], p = .004). At

TABLE 4
Cybersickness measures by exposure day in the Repeated Exposure Condition.

	Day 1	Day 2	Day 3	Sig
ADS	2.75 (*2.11*)	2.03 (*1.83*)	1.47 (*1.70*)	**<.001**
SSQ-O	33.22 (*23.46*)	27.20 (*23.32*)	22.52 (*21.48*)	**.036**
SSQ-D	45.04 (*47.86*)	33.57 (*47.37*)	27.84 (*37.70*)	.078
SSQ-N	48.26 (*35.07*)	32.83 (*37.59*)	26.38 (*34.60*)	**<.001**
SSQ-T	47.41 (*35.62*)	35.31 (*37.09*)	28.93 (*32.06*)	**.005**

All violate sphericity; used Greenhouse-Geisser

TABLE 5
Pairwise comparisons between Repeated Exposure days.

	Day 1-2		Day 2-3		Day 1-3	
	Mean Diff.	Sig	Mean Diff.	Sig	Mean Diff.	Sig
ADS	0.72	**.004**	0.56	**.002**	1.29	**<.001**
SSQ-O	6.02	.154	4.68	.059	10.70	**.023**
SSQ-D	11.46	.160	5.73	.262	17.20	**.049**
SSQ-N	15.43	**.003**	6.45	.051	21.89	**<.001**
SSQ-T	12.10	**.039**	6.38	.058	18.48	**.003**

TABLE 6
ADS means and standard deviations of the Repeated Exposure Days and the Single Exposure Day across the 20 Minutes of VR exposure.

	Repeated Exposure Restricted FOV			Full FOV	Single Exposure
	Day 1	Day 2	Day 3	Day 4	Full FOV
Min 0	0.32 (*1.12*)	0.12 (*0.41*)	0.06 (*0.34*)	0.10 (*0.30*)	0.24 (*0.57*)
Min 4	0.90 (*1.36*)	1.18 (*1.57*)	0.87 (*1.54*)	1.15 (*1.72*)	1.71 (*1.94*)
Min 8	3.00 (*2.77*)	1.97 (*2.23*)	1.50 (*2.02*)	1.65 (*1.82*)	3.43 (*2.57*)
Min 12	3.76 (*2.91*)	2.69 (*2.49*)	1.97 (*2.14*)	2.06 (*2.06*)	4.68 (*2.89*)
Min 16	4.16 (*2.99*)	3.04 (*2.58*)	2.12 (*2.34*)	2.40 (*2.46*)	5.09 (*2.94*)
Min 20	4.37 (*2.97*)	3.19 (*2.67*)	2.29 (*2.56*)	2.50 (*2.61*)	5.62 (*2.93*)

minute 16, Day 1 was significantly higher than Day 2 (M_{diff} = 1.12, 95% CI: [0.41, 1.82], p = .003) and Day 3 (M_{diff} = 2.04, 95% CI: [1.22, 2.87], $p < .001$), and Day 2 was significantly higher than Day 3 (M_{diff} = 0.93, 95% CI: [0.42, 1.43], $p <$ .001). At minute 20, Day 1 was significantly higher than Day 2 (M_{diff} = 1.18, 95% CI: [0.51, 1.85], p = .001) and Day 3 (M_{diff} = 2.07, 95% CI: [1.25, 2.89], $p < .001$), and Day 2 was significantly higher than Day 3 (M_{diff} = 0.90, 95% CI: [0.32, 1.47], p = .003). Figure 5 illustrates these differences across Days and Times.

Taken together, the results reported in this section support Hypothesis 1: cybersickness experienced when using FOV restriction is reduced across repeated exposures.

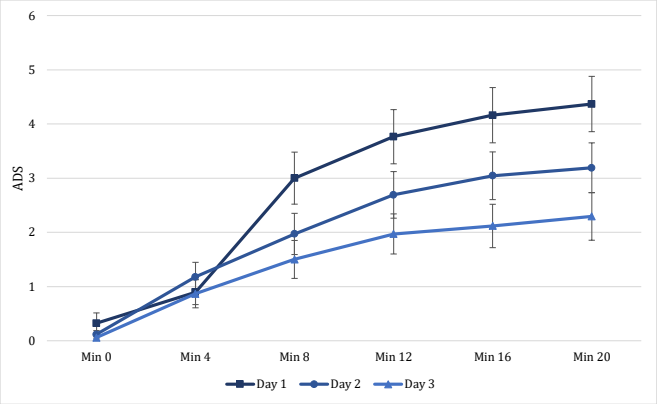

Fig. 5. ADS of Days 1-3 of the Repeated Exposure Condition across Time of the VR Experience. Error bars are standard error.

TABLE 7
Pairwise comparisons of ADS of Repeated Exposure days with FOV restriction across the 20 Minutes of VR exposure.

	Day 1-2		Day 2-3		Day 1-3	
	Mean Diff.	Sig	Mean Diff.	Sig	Mean Diff.	Sig
Min 0	0.21	.147	0.06	.535	0.26	.203
Min 4	-0.28	.238	0.31	.145	0.03	.923
Min 8	1.03	**.002**	0.47	.059	1.50	**<.001**
Min 12	1.07	**.003**	0.72	**.004**	1.79	**<.001**
Min 16	1.12	**.003**	0.93	**<.001**	2.04	**<.001**
Min 20	1.18	**.001**	0.90	**.003**	2.07	**<.001**

5.3.1 Repeated Exposure Recovery Prior to Additional Sessions

Additionally, to determine if there were any lasting cybersickness symptoms from previous days of VR, pre-VR SSQ scores were evaluated using a repeated measures MANOVA with Day (1-4) as the independent variable. The effect of Day on pre-VR SSQ scores was not significant $F(9, 25)$ = 1.53, p = .192; Wilks's Λ = 0.645, η_p^2 = 0.355. The total score of SSQ and all subscales violated sphericity, so a Greenhouse-Geisser correction was utilized. Univariate tests indicated that there were no significant differences in pre-VR scores for total scores, $F(1.47, 48.63)$ = 0.457, p = .577, η_p^2 = 0.014, SSQ-Nausea, $F(1.97, 64.94)$ = 1.384, p = .258, η_p^2 = 0.040, SSQ-Oculomotor, $F(1.84, 60.76)$ = 0.386, p = .664, η_p^2 = 0.012, or SSQ-Disorientation, $F(1.60, 52.74)$ = 0.226, p = .748, η_p^2 = 0.007, indicating carryover effects were not detected.

5.4 Generalization of Repeated Exposure FOV Restriction

Cybersickness experienced in the Repeated Exposure Condition on Day 4 was compared to the Single Exposure Condition using independent samples one-tail t-tests to determine if CARE that occurred with FOV restriction generalized to a full-FOV experience, shown in Table 8. All measures violated Levene's Test of Equality of Variances; therefore, subsequent analyses used equal variances not assumed. Those on Day 4 of the Repeated Exposure Condition reported significantly lower ADS (M = 1.64, SD = 1.68) than those in the Single Exposure Condition (M = 3.46, SD = 2.05, $t(78.5)$ = 4.80, $p < .001$, d = 0.94), which is illustrated in Figure 3. The total SSQ scores were significantly lower in the Repeated Exposure Condition (M = 25.52, SD = 25.07) than those in the Single Exposure Condition (M = 50.73, SD = 38.46, $t(93.13)$ = 3.99, $p < .001$, d = 0.75). Analyses of the SSQ subscales (Figure 4) indicated that those in the Repeated Exposure Condition reported significantly lower levels of Oculomotor (M = 20.73, SD = 18.60), Disorientation (M = 22.52, SD = 28.47), and Nausea (M = 23.57, SD = 26.50) than those in the Single Exposure Condition (SSQ-O; M = 33.18, SD = 26.80, $t(89.58)$ = 2.74, p = .004, d = 0.51) (SSQ-D; M = 49.63, SD = 47.65, $t(97.15)$ = 3.60, $p < .001$, d = 0.64) (SSQ-N; M = 53.65, SD = 40.21, $t(92.57)$ = 4.53, $p < .001$, d = 0.85).

TABLE 8
Comparison between Repeated Exposure Day 4 and the Single Exposure Day to evaluate CARE generalization.

	Repeated Exposure Full FOV Day 4 n = 34	Single Exposure Full FOV n = 69	Sig	Cohen's d
ADS	1.64 (*1.68*)	3.46 (*2.05*)	**<.001**	0.94 (L)
SSQ-O	20.76 (*18.60*)	33.18 (*26.80*)	**.004**	0.51 (M)
SSQ-D	22.52 (*28.47*)	49.63 (*47.65*)	**<.001**	0.64 (M)
SSQ-N	23.57 (*26.49*)	53.65 (*40.21*)	**<.001**	0.83 (L)
SSQ-T	25.52 (*25.07*)	50.73 (*38.46*)	**<.001**	0.73 (M)

All failed Levene's; used Equal Variances not Assumed

A repeated measures MANOVA was conducted to assess if changes in discomfort scores across time points were different on Day 4 of the Repeated Exposure Condition and the Single Exposure Condition. Levene's Test of Equality of Error Variances shows violations for minute 8, 12, and 16; therefore, a square root transformation was applied. The resulting transformation shows no violations of Levene's

Test of Equality of Error Variances. This transformed data was used for the following tests, but the untransformed means and standard deviations can be found in Table 6. The results indicate a significant effect of Time, $F(5,97) = 54.88$, $p < .001$; Wilks's $\Lambda = 0.261$, $\eta_p^2 = 0.739$, and a significant interaction of Exposure Condition and Time, $F(5,97) = 4.60$, $p < .001$; Wilks's $\Lambda = 0.808$, $\eta_p^2 = 0.192$. All measures violated sphericity. Therefore, a Greenhouse-Geisser correction is used for all other measures. The univariate tests indicated a significant effect of Time, $F(2.3, 236.0) = 157.37$, $p < .001$, $\eta_p^2 = 0.609$, and the interaction of Exposure Condition and Time, $F(2.4, 236.0) = 11.95$, $p < .001$, $\eta_p^2 = 0.099$. The between-subjects effect of Exposure Condition was also significant, $F(1, 101) = 15.03$, $p < .001$, $\eta_p^2 = 0.190$.

Pairwise comparisons (Table 9) further show that there were no significant differences of ADS at minute 0 or at minute 4. Those in the Single Exposure Condition had significantly higher ADS than those in Day 4 of the Repeated Exposure Condition during minute 8 ($M_{diff} = 0.62$, 95% CI: [0.26, 0.97], $p < .001$), minute 12 ($M_{diff} = 0.78$, 95% CI: [0.41,1.15], $p < .001$), minute 16 ($M_{diff} = 0.79$, 95% CI: [0.41, 1.17], $p < .001$), and minute 20 ($M_{diff} = 0.90$, 95% CI: [0.51, 1.28], $p < .001$). Figure 6 illustrates these differences between the Exposure Conditions and across Times.

Collectively, the results presented in this section support Hypothesis 2: individuals who repeatedly experienced VR with FOV restriction have lower levels of cybersickness when exposed to full FOV VR, compared to individuals without the repeated VR experience.

TABLE 9
Pairwise comparisons of ADS of the Single Exposure Condition and Repeated Exposure Day 4 across the 20 Minutes of VR exposure.

	Single Exposure - Day 4	
	Mean Diff.	Sig
Min 0	0.09	.292
Min 4	0.26	.131
Min 8	0.62	**<.001**
Min 12	0.78	**<.001**
Min 16	0.79	**<.001**
Min 20	0.90	**<.001**

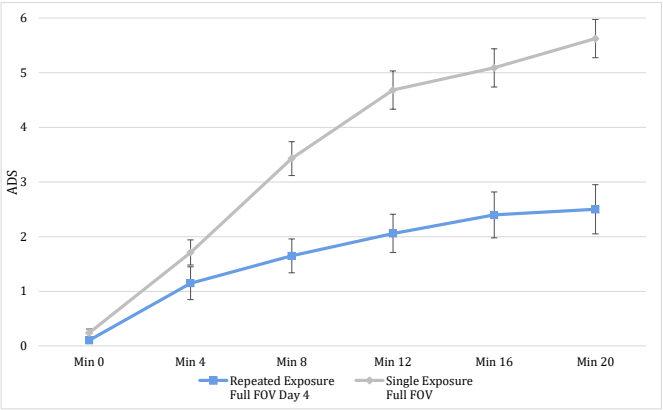

Fig. 6. ADS of Day 4 of the Repeated Exposure Condition and Single Exposure Condition across Time of the VR Experience. Error bars are standard error.

6 Discussion

Past work has shown that reduced levels of cybersickness occur after repeated exposure to VR [1], [13], [14], [17], [18], [19], [20], [21], [22], an effect which we have named CARE. CARE offers a viable solution to ultimately minimizing cybersickness. However, the initial sickness during CARE is unpleasant and discourages some users from trying VR again. This study shows that CARE can occur while restricting FOV to minimize cybersickness. Moreover, the benefits of CARE acquired with restricted FOV persist even upon experiencing full FOV. These results highlight a new method for reducing cybersickness levels via repeated exposures with minimal discomfort.

The current work indicates that those using FOV restriction on Day 1 of the Repeated Exposure Condition experience significantly less cybersickness than the non-restricted FOV Single Exposure Condition, aligning with previous work [7], [11], [30], [31]. However, these significant findings are only present in the cybersickness measure of final FMS score and marginally so in ADS. On average, the full FOV participants could last 16 minutes and 17 seconds in the VR experience, while the FOV-restricted participants lasted 16 minutes and 58 seconds in VR. This lack of significant difference in time caused the ADS measure to be only marginally different between the Day 1 Repeated Exposure Group and the Single Exposure Group. Further, no significant differences exist for any SSQ subscales or total score, as shown in Table 3 and Figure 4. Some previous work has also found significant differences in final FMS score and ADS but no differences in the SSQ total score or any of its subscales [12], [30], [34]. At first, these results may seem at odds with one another. However, the FMS and the SSQ represent very different aspects of cybersickness. FMS is a quick and immersive single-item measure of general feelings of motion sickness used by cybersickness researchers [23], [40]. Several studies have reported the FMS and similar single-item immersed measures as discomfort scores, operationalizing general discomfort instead of cybersickness [10], [12], [13], [29], [34]. However, general discomfort is a part of cybersickness, not the entire picture, as indicated by its use in the SSQ and other post-VR cybersickness measures [23], [24]. The SSQ is symptom-specific and can only be measured outside the VR experience [41]. While able to measure specific symptoms post-exposure, the SSQ fails to capture general feelings of discomfort during the VR experience, resulting in only a partial picture [23], [24], [41], [44]. The current study shows a high correlation between ADS and the total SSQ score (Table 2), as well as a high correlation between the final FMS score and all SSQ subscales and the SSQ total score, which is available in the Open Science Framework [35]. While highly correlated, these measures explore different aspects of cybersickness and, when jointly analyzed, construct a more comprehensive picture. Therefore, FOV restrictions, compared to the full FOV experience, show a decrease in cybersickness severity and are felt during the VR exposure but may not be symptom specific.

CARE in this study occurred while restricting FOV, supporting Hypothesis 1, whereas prior work on CARE has used the display's full FOV [14], [19], [22]. Cybersickness levels decreased across the three repeated exposure

days, indicating CARE occurred while restricting FOV. SSQ subscales showed an across-the-board reduction in cybersickness symptoms from Days 1 to 3, which follows previous literature with full FOV VR experiences [14], [23], [24]. When looking at the differences in ADS across the 20 minute VR experience, it is clear that participants on all three days stay roughly equal in sickness levels and at approximately 8 minutes began to experience significantly different levels of cybersickness. These participants experienced less intense levels of cybersickness through repeated exposure, as shown in Table 7 and Figure 5. While the exact mechanism behind CARE with restricted FOV in the present study requires further research, earlier work has proposed several theories as to why repeated exposure may reduce cybersickness. One of these theories is the sensory rearrangement theory. It hypothesizes that each individual has an internal record of previous motion experienced and what that motion feels like when anticipating movement; however, VR exposure is in conflict with this record, producing cybersickness. But, with repeated exposures to the new sensory arrangements in VR, more new patterns are stored so less sickness is experienced in future VR sessions [14], [25], [45]. Sensory adaptation relies on a similar basis of sensory rearrangement theory, where the conflict may be present but repeated exposure decreases sensitivity to the conflict [14], [19], [21]. A final theory is habituation, where users are able to habituate to the visually induced motion through repeated exposure [14], [19], [20]. Another theory is the postural control theory, which proposes that cybersickness is preceded by increased postural instability. New VR users are less able to control their body movements in the new VR space, leading to sickness. Repeated exposure allows users to develop better strategies to maintain good posture [14], [46]. Another theory suggests that improved task performance in the VR experience leads to less scene instability, decreasing cybersickness [14], [19]. Increased familiarity is associated with increased task performance, leading to reduced anxiety, which is positively correlated with cybersickness [14], [20], [24]. Repeated exposure could also allow individuals to learn how to minimize sickness-inducing movements, as behavioral adaptation hypothesizes [14], [19]. Additionally, prior work has indicated that expectation effects are also present when individuals have VR and video game experience, which is associated with lower cybersickness levels [14], [23], [24]. While unbalanced sample sizes in the current work prevent direct comparisons between those with VR experience (16.5%) and without, or those with video game experience (95.2%) and without (Table 1), there were no significant correlations between the average hours of video games per week and any other variables, except gender (Table 2). While the theory driving this phenomenon in the present study requires more research, the continued reduction of cybersickness symptoms across all three days indicates CARE occurred while FOV was restricted. Additionally, carryover effects of previous days' sickness levels were absent, as shown by the pre-VR SSQ data, demonstrating that participants fully recovered from cybersickness by the following visit. This complete recovery is critical because cybersickness levels can last several hours or days in more extreme circumstances and could compound the current day's cybersickness severity [24], [47].

Furthermore, the results indicate that CARE with restricted FOV can generalize to an experience with full FOV. Repeated Exposure participants reported lower ADS and SSQ scores than Single Exposure participants during the full-FOV VR experience. Repeated Exposure participants also reported lower sickness across all SSQ subscales (as well as total sickness scores) than Single Exposure participants, supporting Hypothesis 2. Previous work has shown mixed results regarding whether CARE is experience-specific [1], [14] The current study shows that when experiencing the full FOV environment, those in the Repeated Exposure Condition roughly maintained cybersickness levels, rather than continuing to decrease relative to Day 3 or reverting to pre-CARE levels. These results suggest that the Day 4 full FOV generalization of CARE developed with FOV restriction is not an extension of the CARE process. This conclusion supports the theory that CARE is not experience-specific.

6.1 Limitations and Future Directions

Future work should include a full FOV repeated exposure condition to determine if CARE and generalization are affected by the presence of FOV restriction. CARE with restricted FOV clearly generalized to a subsequent exposure with full FOV. However, more substantial CARE could occur if participants did not experience FOV restriction at all, since changing context from a restricted FOV experience to a full FOV experience might inhibit generalization. Additionally, a measure of task load and physiological assessments should be included in future research to better assess any compromises the FOV restriction may be evoking. Such a condition would help establish whether there are trade-offs to CARE with FOV restriction or without, besides the obvious difference in discomfort during repeated exposures.

Future work should also investigate whether CARE is affected by stimulus intensity or exposure duration. For example, it is unknown whether length of VR exposure or visual intensity during exposure affects CARE. If short and mild repeated exposures cause robust reductions of cybersickness, then users may be able to have reduced sickness levels from repeated exposure without experiencing significant cybersickness initially. A study of this nature would allow researchers to identify ideal conditions for CARE in terms of comfort in single sessions and generalization to other experiences.

Other cybersickness mitigation techniques should be considered in future work to determine the optimal conditions to reduce cybersickness and maximize CARE. Examples of this could include snap turning (rotational jumps which exclude intermediate angles, thereby reducing visual motion), which causes less sickness than smooth turning [9], [28], [43], and locomotion type, where teleportation-style movements are associated with less sickness than joystick-based movements [26], [27], [48]. Including user movement data in future work could benefit research regarding the mechanism behind reduced cybersickness. It is unknown whether CARE would generalize across interfaces, which would be another rich area for research. Future work should also assess the retention of CARE, as previous research has

indicated that CARE can persist from a week to up to four months post-exposure [14], [20].

7 Conclusion

Virtual reality has opened the doors for many experiences that would be impossible to explore without it. While cybersickness may be one of the most significant obstructions to the widespread adoption of VR, there are unmistakable ways to reduce sickness. Previous work has shown that cybersickness decreases after repeated exposure [14], [23], [24]. The current work builds on that literature by showing that significant reductions of cybersickness through repeated exposures can occur with minimal experience of cybersickness.

References

[1] I. Adhanom, S. Halow, E. Folmer, and P. MacNeilage, "VR Sickness Adaptation With Ramped Optic Flow Transfers From Abstract To Realistic Environments," *Frontiers in Virtual Reality*, vol. 3, no. May, pp. 1–13, 5 2022. [Online]. Available: https://www.frontiersin.org/articles/10.3389/frvir.2022.848001/full

[2] S. Rangelova, D. Motus, and E. André, "Cybersickness Among Gamers: An Online Survey," in *Advances in Intelligent Systems and Computing*, 2020, vol. 973, pp. 192–201. [Online]. Available: http://link.springer.com/10.1007/978-3-030-20476-1_20

[3] P. Campo-Prieto, J. M. Cancela, and G. Rodríguez-Fuentes, "Immersive virtual reality as physical therapy in older adults: present or future (systematic review)," *Virtual Reality*, vol. 25, no. 3, pp. 801–817, 9 2021. [Online]. Available: https://doi.org/10.1007/s10055-020-00495-x

[4] J. M. Davila Delgado, L. Oyedele, P. Demian, and T. Beach, "A research agenda for augmented and virtual reality in architecture, engineering and construction," *Advanced Engineering Informatics*, vol. 45, no. June, p. 101122, 8 2020. [Online]. Available: https://doi.org/10.1016/j.aei.2020.101122

[5] K. Grinyer and R. J. Teather, "Effects of Field of View on Dynamic Out-of-View Target Search in Virtual Reality," in *2022 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*. IEEE, 3 2022, pp. 139–148. [Online]. Available: https://ieeexplore.ieee.org/document/9756794/

[6] K. Stanney and G. Salvendy, "Aftereffects and Sense of Presence in Virtual Environments: Formulation of a Research and Development Agenda," *International Journal of Human-Computer Interaction*, vol. 10, no. 2, pp. 135–187, 6 1998. [Online]. Available: http://www.tandfonline.com/doi/abs/10.1207/s15327590ijhc1002_3

[7] G. Zhao, J. Orlosky, S. Feiner, P. Ratsamee, and Y. Uranishi, "Mitigation of VR Sickness During Locomotion With a Motion-Based Dynamic Vision Modulator," *IEEE Transactions on Visualization and Computer Graphics*, vol. 29, no. 10, pp. 4089–4103, 10 2023. [Online]. Available: https://ieeexplore.ieee.org/document/9793626/

[8] J. W. Kelly, L. A. Cherep, A. F. Lim, T. Doty, and S. B. Gilbert, "Who Are Virtual Reality Headset Owners? A Survey and Comparison of Headset Owners and Non-Owners," in *2021 IEEE Virtual Reality and 3D User Interfaces (VR)*. IEEE, 3 2021, pp. 687–694. [Online]. Available: https://ieeexplore.ieee.org/document/9417669/

[9] S. Ang and J. Quarles, "GingerVR: An Open Source Repository of Cybersickness Reduction Techniques for Unity," in *2020 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW)*. IEEE, 3 2020, pp. 460–463. [Online]. Available: https://ieeexplore.ieee.org/document/9090447/

[10] M. Al Zayer, I. B. Adhanom, P. MacNeilage, and E. Folmer, "The Effect of Field-of-View Restriction on Sex Bias in VR Sickness and Spatial Navigation Performance," in *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*. New York, NY, USA: ACM, 5 2019, pp. 1–12. [Online]. Available: https://dl.acm.org/doi/10.1145/3290605.3300584

[11] J. W. Kelly, T. A. Doty, S. B. Gilbert, and M. C. Dorneich, "Field of view restriction and snap turning as cybersickness mitigation tools," *PsyArxiv*, pp. 1–9, 2023. [Online]. Available: https://doi.org/10.31234/osf.io/ksw63

[12] F. Wu and E. Suma Rosenberg, "Adaptive Field-of-view Restriction: Limiting Optical Flow to Mitigate Cybersickness in Virtual Reality," in *Proceedings of the 28th ACM Symposium on Virtual Reality Software and Technology*. New York, NY, USA: ACM, 11 2022, pp. 1–11. [Online]. Available: https://dl.acm.org/doi/10.1145/3562939.3565611

[13] Y.-X. Lin, R. Venkatakrishnan, R. Venkatakrishnan, E. Ebrahimi, W.-C. Lin, and S. V. Babu, "How the Presence and Size of Static Peripheral Blur Affects Cybersickness in Virtual Reality," *ACM Transactions on Applied Perception*, vol. 17, no. 4, pp. 1–18, 10 2020. [Online]. Available: https://dl.acm.org/doi/10.1145/3419984

[14] S. Palmisano and R. Constable, "Reductions in sickness with repeated exposure to HMD-based virtual reality appear to be game-specific," *Virtual Reality*, vol. 26, no. 4, pp. 1373–1389, 12 2022. [Online]. Available: https://doi.org/10.1007/s10055-022-00634-6

[15] J. Golding, "Motion sickness," in *Handbook of Clinical Neurology*, 1st ed. Elsevier B.V., 2016, vol. 137, pp. 371–390. [Online]. Available: http://dx.doi.org/10.1016/B978-0-444-63437-5.00027-3

[16] B. D. Lawson, "Technology Management and User Acceptance of Virtual Environment Technology," in *Handbook of Virtual Environments*. Boca Raton, FL: CRC Press, 9 2014, no. January, pp. 523–534. [Online]. Available: https://www.taylorfrancis.com/books/9781466511859/chapters/10.1201/b17360-29

[17] J. N. Bailenson and N. Yee, "A Longitudinal Study of Task Performance, Head Movements, Subjective Report, Simulator Sickness, and Transformed Social Interaction in Collaborative Virtual Environments," *Presence: Teleoperators and Virtual Environments*, vol. 15, no. 6, pp. 699–716, 12 2006. [Online]. Available: https://direct.mit.edu/pvar/article/15/6/699-716/18655

[18] S. C. Beadle, E. R. Muth, and C. C. Pagano, "Using head-mounted displays to examine adaptation and calibration under varying perturbations," *Displays*, vol. 66, no. August 2020, p. 101985, 1 2021. [Online]. Available: https://doi.org/10.1016/j.displa.2020.101985

[19] K. Hill and P. Howarth, "Habituation to the side effects of immersion in a virtual environment," *Displays*, vol. 21, no. 1, pp. 25–30, 3 2000. [Online]. Available: https://linkinghub.elsevier.com/retrieve/pii/S0141938200000299

[20] P. A. Howarth and S. G. Hodder, "Characteristics of habituation to motion in a virtual environment," *Displays*, vol. 29, no. 2, pp. 117–123, 3 2008. [Online]. Available: https://linkinghub.elsevier.com/retrieve/pii/S0141938207000960

[21] D. Risi and S. Palmisano, "Effects of postural stability, active control, exposure duration and repeated exposures on HMD induced cybersickness," *Displays*, vol. 60, no. August, pp. 9–17, 12 2019. [Online]. Available: https://doi.org/10.1016/j.displa.2019.08.003

[22] M. L. van Emmerik, S. C. de Vries, and J. E. Bos, "Internal and external fields of view affect cybersickness," *Displays*, vol. 32, no. 4, pp. 169–174, 10 2011. [Online]. Available: http://dx.doi.org/10.1016/j.displa.2010.11.003

[23] A. Kemeny, J.-R. Chardonnet, and F. Colombet, *Getting Rid of Cybersickness*. Cham: Springer International Publishing, 2020. [Online]. Available: http://link.springer.com/10.1007/978-3-030-59342-1

[24] K. Stanney, B. D. Lawson, B. Rokers, M. Dennison, C. Fidopiastis, T. Stoffregen, S. Weech, and J. M. Fulvio, "Identifying Causes of and Solutions for Cybersickness in Immersive Technology: Reformulation of a Research and Development Agenda," *International Journal of Human–Computer Interaction*, vol. 36, no. 19, pp. 1783–1803, 11 2020. [Online]. Available: https://doi.org/10.1080/10447318.2020.1828535

[25] B. Keshavarz, A. E. Philipp-Muller, W. Hemmerich, B. E. Riecke, and J. L. Campos, "The effect of visual motion stimulus characteristics on vection and visually induced motion sickness," *Displays*, vol. 58, no. July 2018, pp. 71–81, 7 2019. [Online]. Available: https://doi.org/10.1016/j.displa.2018.07.005

[26] A. Caputo, M. Zancanaro, and A. Giachetti, "Eyes on Teleporting: Comparing Locomotion Techniques in Virtual Reality with Respect to Presence, Sickness and Spatial Orientation," in *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*. Springer Nature Switzerland, 2023, vol. 14144 LNCS, pp. 547–566. [Online]. Available: http://dx.doi.org/10.1007/978-3-031-42286-7_31

[27] K. Rahimi, C. Banigan, and E. D. Ragan, "Scene Transitions and Teleportation in Virtual Reality and the Implications for Spatial

Awareness and Sickness," *IEEE Transactions on Visualization and Computer Graphics*, vol. 26, no. 6, pp. 2273–2287, 6 2020. [Online]. Available: https://ieeexplore.ieee.org/document/8554159/

[28] A. N. Ryge, C. Vollmers, J. S. Hvass, L. K. Andersen, T. Berthelsen, J. R. Bruun-Pedersen, N. C. Nilsson, and R. Nordahl, "A Preliminary Investigation of the Effects of Discrete Virtual Rotation on Cybersickness," in *2018 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*. IEEE, 3 2018, pp. 675–676. [Online]. Available: https://ieeexplore.ieee.org/document/8446206/

[29] I. B. Adhanom, N. Navarro Griffin, P. MacNeilage, and E. Folmer, "The Effect of a Foveated Field-of-view Restrictor on VR Sickness," in *2020 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*. IEEE, 3 2020, pp. 645–652. [Online]. Available: https://ieeexplore.ieee.org/document/9089437/

[30] A. S. Fernandes and S. K. Feiner, "Combating VR sickness through subtle dynamic field-of-view modification," in *2016 IEEE Symposium on 3D User Interfaces (3DUI)*. IEEE, 3 2016, pp. 201–210. [Online]. Available: http://ieeexplore.ieee.org/document/7460053/

[31] Y. Y. Kim, E. N. Kim, M. J. Park, K. S. Park, H. D. Ko, and H. T. Kim, "The Application of Biosignal Feedback for Reducing Cybersickness from Exposure to a Virtual Environment," *Presence: Teleoperators and Virtual Environments*, vol. 17, no. 1, pp. 1–16, 2 2008. [Online]. Available: https://direct.mit.edu/pvar/article/17/1/1-16/18706

[32] J.-W. Lin, H. Duh, D. Parker, H. Abi-Rached, and T. Furness, "Effects of field of view on presence, enjoyment, memory, and simulator sickness in a virtual environment," in *Proceedings IEEE Virtual Reality 2002*, no. January. IEEE Comput. Soc, 2002, pp. 164–171. [Online]. Available: http://ieeexplore.ieee.org/document/996519/

[33] A. Seay, D. Krum, L. Hodges, and W. Ribarsky, "Simulator sickness and presence in a high FOV virtual environment," in *Proceedings IEEE Virtual Reality 2001*, vol. 65, no. 2. IEEE Comput. Soc, 2001, pp. 299–300. [Online]. Available: http://ieeexplore.ieee.org/document/913806/

[34] F. Wu, G. S. Bailey, T. Stoffregen, and E. Suma Rosenberg, "Don't Block the Ground: Reducing Discomfort in Virtual Reality with an Asymmetric Field-of-View Restrictor," in *Symposium on Spatial User Interaction*. New York, NY, USA: ACM, 11 2021, pp. 1–10. [Online]. Available: https://dl.acm.org/doi/10.1145/3485279.3485284

[35] T. A. Doty, J. W. Kelly, M. C. Dorneich, and S. B. Gilbert, "Cybersickness adaptation with field-of-view restriction," 2024. [Online]. Available: https://osf.io/tqf2s/

[36] J. F. Golding, "Motion sickness susceptibility questionnaire revised and its relationship to other forms of sickness," *Brain Research Bulletin*, vol. 47, no. 5, pp. 507–516, 11 1998. [Online]. Available: https://linkinghub.elsevier.com/retrieve/pii/S0361923098000914

[37] ——, "Motion sickness susceptibility," *Autonomic Neuroscience*, vol. 129, no. 1-2, pp. 67–76, 10 2006. [Online]. Available: https://linkinghub.elsevier.com/retrieve/pii/S1566070206002128

[38] B. Keshavarz, R. Saryazdi, J. L. Campos, and J. F. Golding, "Introducing the VIMSSQ: Measuring susceptibility to visually induced motion sickness," *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, vol. 63, no. 1, pp. 2267–2271, 11 2019. [Online]. Available: http://journals.sagepub.com/doi/10.1177/1071181319631216

[39] J. F. Golding, A. Rafiq, and B. Keshavarz, "Predicting Individual Susceptibility to Visually Induced Motion Sickness by Questionnaire," *Frontiers in Virtual Reality*, vol. 2, no. March, 2021.

[40] B. Keshavarz and H. Hecht, "Validating an Efficient Method to Quantify Motion Sickness," *Human Factors: The Journal of the Human Factors and Ergonomics Society*, vol. 53, no. 4, pp. 415–426, 8 2011. [Online]. Available: http://journals.sagepub.com/doi/10.1177/0018720811403736

[41] R. S. Kennedy, N. E. Lane, K. S. Berbaum, and M. G. Lilienthal, "Simulator Sickness Questionnaire: An Enhanced Method for Quantifying Simulator Sickness," *The International Journal of Aviation Psychology*, vol. 3, no. 3, pp. 203–220, 7 1993. [Online]. Available: http://www.tandfonline.com/doi/abs/10.1207/s15327108ijap0303_3

[42] Meta, "Jurassic World Aftermath Collection," 2020. [Online]. Available: https://www.meta.com/experiences/2708465082504733/

[43] Y. Farmani and R. J. Teather, "Evaluating discrete viewpoint control to reduce cybersickness in virtual reality," *Virtual Reality*, vol. 24, no. 4, pp. 645–664, 12 2020. [Online]. Available: https://doi.org/10.1007/s10055-020-00425-x

[44] V. Sevinc and M. I. Berkman, "Psychometric evaluation of Simulator Sickness Questionnaire and its variants as a measure of cybersickness in consumer virtual environments," *Applied Ergonomics*, vol. 82, no. July 2018, p. 102958, 1 2020. [Online]. Available: https://linkinghub.elsevier.com/retrieve/pii/S0003687019301759

[45] J. T. Reason and J. J. Brand, "Motion sickness." Oxford, England, pp. vii, 310–vii, 310, 1975.

[46] T. A. Stoffregen, L. J. Hettinger, M. W. Haas, M. M. Roe, and L. J. Smart, "Postural instability and motion sickness in a fixed-base flight simulator," *Human Factors*, vol. 42, no. 3, pp. 458–469, 2000.

[47] R. K. Champney, K. M. Stanney, P. A. K. Hash, L. C. Malone, R. S. Kennedy, and D. E. Compton, "Recovery From Virtual Environment Exposure: Expected Time Course of Symptoms and Potential Readaptation Strategies," *Human Factors: The Journal of the Human Factors and Ergonomics Society*, vol. 49, no. 3, pp. 491–506, 6 2007. [Online]. Available: http://journals.sagepub.com/doi/10.1518/001872007X200120

[48] L. A. Cherep, A. F. Lim, J. W. Kelly, D. Acharya, A. Velasco, E. Bustamante, A. G. Ostrander, and S. B. Gilbert, "Spatial cognitive implications of teleporting through virtual environments." *Journal of Experimental Psychology: Applied*, vol. 26, no. 3, pp. 480–492, 9 2020. [Online]. Available: https://doi.apa.org/doi/10.1037/xap0000263

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