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Field of view restriction and snap turning as cybersickness mitigation tools

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

Abstract—Multiple tools are available to reduce cybersickness (sickness caused by virtual reality), but past research has not investigated the combined effects of multiple mitigation tools. Field of view (FOV) restriction limits peripheral vision during self-motion, and ample evidence supports its effectiveness for reducing cybersickness. Snap turning involves discrete rotations of the user's perspective without presenting intermediate views, although reports on its effectiveness at reducing cybersickness are limited and equivocal. Both mitigation tools reduce the visual motion that can cause cybersickness. The current study (N = 201) investigated the individual and combined effects of FOV restriction and snap turning on cybersickness when playing a consumer virtual reality game. FOV restriction and snap turning in isolation reduced cybersickness compared to a control condition without mitigation tools. Yet, the combination of FOV restriction and snap turning did not further reduce cybersickness beyond the individual tools in isolation, and in some cases the combination of tools led to cybersickness similar to that in the no mitigation control. These results indicate that caution is warranted when combining multiple cybersickness mitigation tools, which can interact in unexpected ways.

Index Terms—Cybersickness, Virtual reality, Motion sickness, Field of view restriction, Snap turning.

1 Introduction

CYBERSICKNESS, which includes symptoms such as nausea, disorientation, sweating, headache, and eyestrain caused by exposure to virtual reality (VR) [1], [2], [3], [4], presents a major barrier to the technology's effectiveness and widespread adoption. Cybersickness affects a large percentage of VR users, and it can occur after a relatively short exposure duration of just 10-20 minutes [5], [6], [7]. The problem may be even more pronounced among certain individuals [8], such as women [9], [10] and people with a history of motion sickness [8], [11], [12]. Many consumer VR applications offer multiple cybersickness mitigation tools. Yet, users are not typically guided as to which or how many mitigation tools to choose. This study evaluates the individual and combined effects of two commonly available cybersickness mitigation tools: field of view (FOV) restriction and snap turning.

One major theory proposes that cybersickness is caused by sensory conflict between body-based and visual motion signals [1], [3], [4], [13]. For example, a VR user sitting on their couch may experience sensory signals from the body (e.g., via proprioception and vestibular inputs) indicating that they are stationary, and visual sensory signals indicating translational and rotational motion through the virtual environment (VE). The conflicting sensory inputs are thought to be at least partially responsible for subsequent cybersickness.

Following the logic behind sensory conflict theory, many cybersickness mitigation tools focus on reducing sensory conflict. For example, FOV restriction (sometimes referred to as vignettes or tunneling) reduces the intensity of visual motion during movement by blurring or blocking the visual periphery, thereby reducing sensory conflict and cybersickness [14], [15], [16], [17], [18], [19], [20], [21]. Snap turning (sometimes referred to as rotation snapping) is another cybersickness mitigation tool whereby visual rotation through the VE occurs in discrete rotational jumps without any visual motion through intermediate orientations [15], [22], [23]. Snap turning is conceptually similar to teleporting, which is a popular locomotion interface that involves discrete translational jumps through the VE, thereby eliminating visual motion when changing position in the VE [24], [25], [26], [27], [28], [29], [30]. The difference between teleporting and snap turning is that teleporting typically affects translational movement, whereas snap turning affects rotational movement.

The current study evaluated the effectiveness of FOV restriction, snap turning, and their combination for reducing cybersickness. VR users, especially those who are most sensitive to motion sickness, may wish to combine multiple cybersickness mitigation tools. Although prior work has examined the effectiveness of FOV restriction and snap turning independently, research has not evaluated the combined effects of using multiple cybersickness mitigation tools.

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2 Related work

2.1 FOV restriction

FOV restriction is intended to reduce cybersickness by limiting or eliminating visual motion in the periphery. Some research indicates that self-motion perception depends more on peripheral vision than on central vision [31], [32], although other findings report equivalent roles of central and peripheral vision [33], [34]. Regardless, blocking peripheral vision is intended to reduce the potential sensory conflict between vision and body-based sensory systems by minimizing visual motion.

FOV restriction has been shown to significantly reduce cybersickness. In one study [16], participants used joystick locomotion to follow a set of waypoints through a virtual world. FOV was either unaltered or dynamically reduced during translations and rotations based on translational speed. At maximum speed, FOV was reduced from approximately 110° diagonal (the native FOV of the Oculus DK2) to an 80° or 90° circular FOV, depending on condition. Combining the two restricted FOV conditions, cybersickness reported during VR exposure was 40% lower with FOV restriction compared to without. Surprisingly, there were no differences when cybersickness was measured after VR exposure using a more symptom-specific measure (the simulator sickness questionnaire, or SSQ [2]).

In another study [17], participants performed a triangle completion task in VR using joystick locomotion. FOV was either unrestricted or dynamically reduced during translations and rotations. At maximum speed, FOV was reduced from approximately 110° diagonal (the native FOV of the HTC Vive) to a 50° circular FOV. FOV restriction reduced cybersickness by 30-70%, measured after VR exposure using the SSQ (values varied depending on whether pre-exposure SSQ was used as a baseline).

Another study measured cybersickness under different levels of FOV restriction in a wide-FOV driving simulator [20]. In general, greater FOV restriction led to lower experienced cybersickness.

One study reported that FOV restriction increased cybersickness compared to an unrestricted condition [35], a finding which diverges from most of the literature. FOV reduction in this study was linked to eye gaze, and the authors speculate that system latency could account for the divergent finding. The study included around 9 participants per condition, so the results warrant replication with a more robust sample.

In summary, FOV restriction appears to be an effective cybersickness mitigation tool. Studies have typically applied FOV restriction during both translational and rotational movements, so it remains unclear whether the benefits of FOV restriction are primarily associated with translation, rotation, or both.

2.2 Snap turning

Snap turning is intended to reduce cybersickness by removing all visual motion associated with rotation through the VE. When using snap turning, the user provides input using a device (usually a joystick, but keyboard, mouse, or other inputs are also possible) which causes instantaneous yaw rotation of the view by a pre-determined discrete angle. Intermediate orientations are skipped, thereby eliminating visual motion altogether.

Although snap turning is an option available on many consumer games, there is scant research on its effectiveness at reducing cybersickness. In one study [22], participants rotated in place using a mouse in order to find and shoot approaching zombies for up to 20 minutes. In one condition, the participant experienced smooth visual rotation based on the mouse input. In the snap turn condition, rotation occurred in discrete 22.5° increments, thereby eliminating visual motion during rotations. The specific rotational increment of 22.5° was chosen through pilot testing, which revealed that larger rotational increments were perceived as disorienting and uncomfortable. Snap turning reduced cybersickness by around 40% compared to smooth turning.

In another study on snap turning [23], participants spent approximately 5 minutes solving puzzles in order to pass through a series of virtual rooms. Half of participants turned smoothly and the other half turned in discrete 30° increments (i.e., snap turning). Cybersickness did not differ between the two turning groups, indicating that snap turning may not be an especially effective cybersickness mitigation tool.

It is unclear why one study found a benefit of snap turning on cybersickness [22] and another study did not [23]. One possibility is that the latter study reported somewhat low cybersickness in both turning conditions (mean total SSQ scores around 25, compared to 50+ in the smooth rotation condition reported elsewhere [22]), which indicates possible floor effects.

3 Study overview and hypotheses

This study independently manipulated two cybersickness mitigation tools, FOV restriction and snap turning, which were either on or off. Key experimental manipulations are depicted in Figure 1. FOV restriction affected translations only and snap turning affected rotations only, which allowed the two tools to be studied in isolation and in combination.

FOV restriction and snap turning have independently been shown to reduce cybersickness compared to control conditions [16], [17], [21], [22]. Yet, significant cybersickness can still occur and increase over time [16], [22] even when using these mitigation tools, and VR users may benefit from combining multiple cybersickness mitigation tools. Therefore, one goal of the current study is to evaluate the combined effects of multiple cybersickness mitigation tools. Furthermore, the effect of snap turning on cybersickness has only been reported in two studies, and with mixed results [22], [23], so further investigation of this mitigation tool is warranted.

It was hypothesized that FOV restriction and snap turning would both independently reduce cybersickness compared to a control condition without mitigation tools. It was also expected that FOV restriction and snap turning together would result in further reduction in cybersickness beyond either mitigation tool alone, as long as floor effects (i.e., very low cybersickness ratings when using an individual mitigation tool) could be avoided. To our knowledge, no prior study has evaluated the combined effects of any cybersickness mitigation tools, so this hypothesis was speculative.

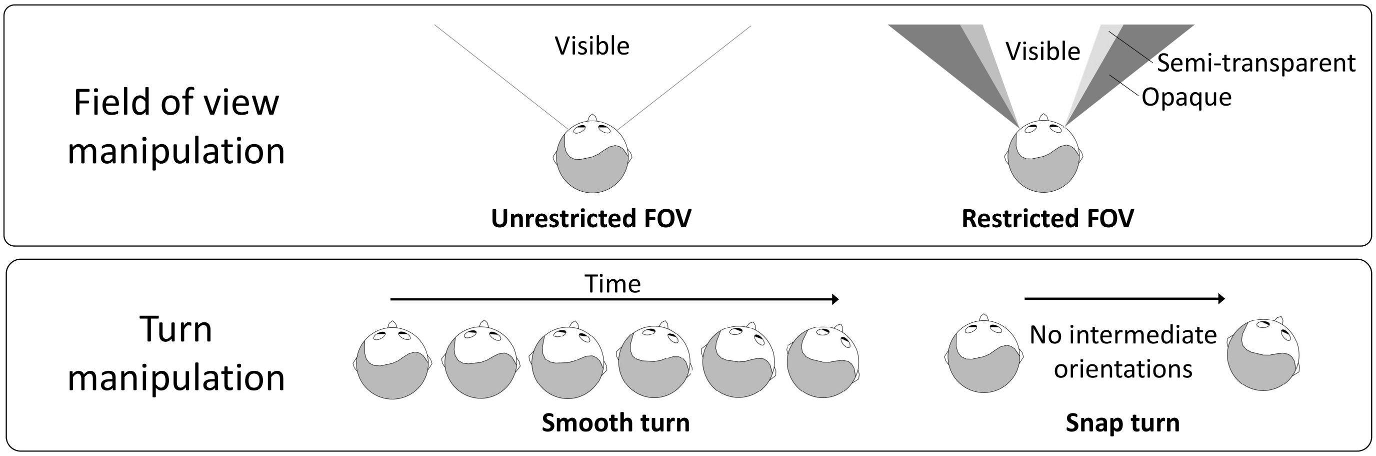

Fig. 1: Overview of key experimental manipulations. Field of view (FOV) manipulation: Unrestricted FOV allowed access to the full FOV afforded by the display, whereas restricted FOV restricted the visible scene during translations to 40° horizontal with an additional 10° of semi-transparent area beyond. Turn manipulation: Smooth turning involved continuous rotation to a new orientation, whereas snap turning involved a discrete orientation jump in increments of 22.5°.

4 METHOD

4.1 Participants

Two hundred and one undergraduate students (118 men, 83 women) at Iowa State University participated in exchange for course credit. Some participants signed up for a multi-day study on adaptation, whereas others signed up for a one-day study. For multi-day participants, the data reported here are only from the first day of exposure, and therefore do not reflect potential adaptation effects (adaptation data from subsequent days are outside the scope of the current study and will be reported elsewhere). Further, the day 1 experience of participants who signed up for the multi-day study was identical to the experience of participants who signed up for the one-day study except for the informed consent form, which specified the number of days involved in the study.

The sample included 52 participants who experienced no cybersickness mitigation techniques, 56 who experienced FOV restriction only, 52 who experienced snap turning only, and 41 who experienced FOV restriction and snap turning together (see Table 1 for more details on participant characteristics). Average participant age was 19.0 years (*SD*=1.1).

4.2 Stimuli and design

The experiment utilized the Quest 2 headset running Jurassic World Aftermath, a consumer VR game available from the Quest store. In this game, the user is tasked with escaping from an abandoned research facility by obtaining information while avoiding detection by roaming dinosaurs. The Quest 2 controllers were used to move through the VE, with the left joystick used to control translations (front/back or sideways strafing) and the right joystick used to control rotations.

The experiment followed a 2 × 2 between-participants design in which FOV restriction and snap turning were either on or off. FOV restriction and snap turning were built in to the consumer game and enabled through game menus. FOV restriction and snap turning were both adjustable in magnitude (e.g., various levels of FOV restriction were available in the game settings), so the researchers identified intermediate values for both and used the selected values throughout the study. The goal of choosing intermediate values was primarily to avoid floor and ceiling effects, so that differences could be detected between conditions.

When FOV restriction was turned off, the participant experienced the VE with the maximum FOV allowed by the display (estimated to be 104° horizontal by 98° vertical). FOV restriction occurred only in the horizontal dimension. Upon deflecting the joystick to initiate translation, FOV restriction shifted from full FOV to maximum restriction in a very short time (approximately 100 milliseconds), irrespective of the user's speed. At its maximum, horizontal peripheral vision was completely obscured (i.e., completely black) beyond a 60° span centered on the participant's head direction. There was a semi-transparent band between 40° and 60° horizontal, and the central 40° was unaltered. Vertical FOV was unaltered. FOV restriction only occurred during translations and did not occur during rotations.

When snap turning was off, the participant rotated smoothly using the joystick at a maximum speed of approximately 180° per second. When snap turning was on, the participant rotated in 22.5° increments each time the joystick was deflected to the side, without experiencing any intermediate orientations. The screen briefly turned black between views when using snap turning.

4.3 Measures of cybersickness

Cybersickness was measured in multiple ways. First, participants completed the SSQ [2], a 16-item questionnaire that asks about potential symptoms on a 4-point scale from 0 (none) to 3 (severe). The SSQ was administered before and after VR exposure. SSQ sub-scores and total score were computed following the original recommendations [2].

Second, participants rated their sickness every 4 minutes during VR exposure and again upon exiting VR using an 11-point scale from 0 (none) to 10 (severe), modeled after the 21-point fast motion sickness (FMS) scale [36]. This measure is herein referred to as FMS, even though the scale range was modified for ease of comprehension. The measure is also quite similar to the 11-point discomfort score used in cybersickness research [16], [18], [21]. FMS data were considered in two ways. One is that the final FMS rating was used as an indicator of cybersickness. The other is that FMS data collected during exposure (i.e., every 4 minutes) were averaged across the entire exposure to create a measure called the average discomfort score (ADS; see Section 5 for more details on ADS calculation) [16], [18], [21].

Third, exposure time was measured from the start of VR exposure to the end of VR exposure (either when 20 minutes elapsed or when the participant withdrew).

4.4 Procedure

Upon arrival at the lab, the participant reviewed and signed the informed consent document. The participant then sat at a computer monitor and completed several survey measures, including demographics, a video game usage questionnaire, the motion sickness susceptibility questionnaire (MSSQ) [37], the visually inducted motion sickness susceptibility questionnaire (VIMSSQ) [12], and the SSQ [2]. The participant was then given basic information about the game they would be playing and how to use the controllers. The researcher then measured the participant's interpupillary distance (IPD) with a ruler, adjusted the headset IPD to the value nearest the participant's measured IPD, and then helped the participant don and adjust the headset. The participant remained seated throughout the VR exposure.

The participant was instructed to play the game for up to 20 minutes or until they could no longer continue due to cybersickness. The researcher asked the participant to rate their sickness on a scale from 0 (none) to 10 (severe) every four minutes during VR exposure, starting upon initial entry into VR. A final measurement was taken when the participant exited VR.

After exiting VR, the participant completed the SSQ and the virtual reality neuroscience questionnaire (VRNQ) [38], which included several questions (on a 7-point scale) about enjoyment and usability.

5 Results

Complete data are available on the Open Science Framework [39]. Participant demographics (gender, MSSQ, and VIMSSQ) are presented in Table 1 along with SSQ total, ADS, final FMS, and exposure time in minutes.

FMS ratings were used to produce the average discomfort score measure (ADS), following past research [16], [18], [21]. ADS calculation assumed that a participant who ended early would have been at least as sick as their final measured FMS, and therefore used that value for any missing measures after early withdrawal from the study. For example, if a participant dropped out after 14 minutes, their final FMS rating taken upon exit would be used for the missing FMS recordings at 16 and 20 minutes. Others [16], [18], [21] have used the maximum possible sickness score (10 in the current study), rather than the final sickness score, for participants who withdraw prematurely. Using the final score seems more reflective of the participant's actual experience.

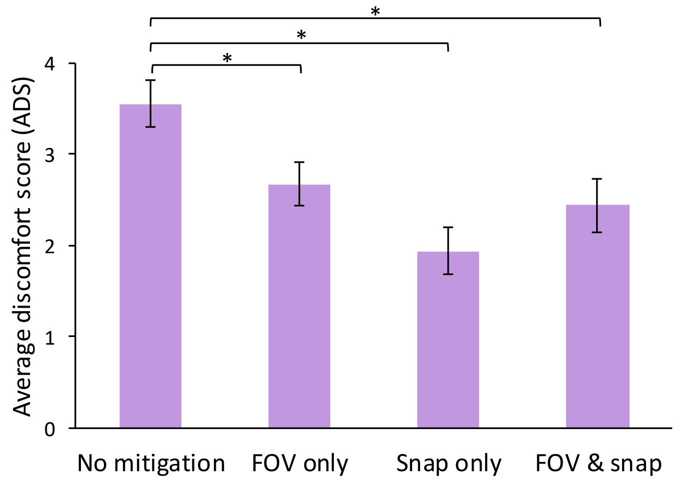

Fig. 2: Mean ADS as a function of condition. Error bars represent +/- 1 SEM. Asterisks indicate a statistically significant difference between conditions.

However, both methods led to identical conclusions with the current data. Finally, an average score was computed across all 20 minutes, and this value represents the ADS measure. Although past research using ADS measured discomfort score rather than FMS, the two measures are quite similar so the substitution is reasonable. Discomfort score measures immediate discomfort, whereas FMS measures immediate sickness. FMS ratings and exposure time are not described separately in this section because ADS uses FMS data and also accounts for differences in exposure time. Supplemental analyses of final FMS and exposure time are provided on the Open Science Framework [39].

Means, standard deviations, and correlations among individual difference measures and key cybersickness measures are shown in Table 2. Due to the significant associations among several variables found here and reported in the literature [9], [11], [40], subsequent statistical analyses include gender, VIMSSQ, and MSSQ as covariates when possible. Controlling for those individual difference variables also helped to ensure that any differences in cybersickness across conditions were due to differences between mitigation conditions and not differences in participant characteristics caused by sampling error.

5.1 ADS

ADS showed minimal skewness (0.36) and the homogeneity of variances assumption was met, $F(3, 197) = 1.91$, $p = .129$. Analysis therefore proceeded using parametric tests.

A 2 (FOV restriction) × 2 (snap turning) ANCOVA was conducted with ADS as the dependent variable and gender, VIMSSQ, and MSSQ as covariates. Estimated marginal means for each of the four conditions are displayed in Figure 2. The main effect of snap turning was statistically significant, $F(1, 194) = 12.13$, $p < .001$, $\eta_p^2 = .059$, as was the interaction between FOV restriction and snap turning, $F(1, 194) = 6.80$, $p = .009$, $\eta_p^2 = .034$. The main effect of FOV restriction was not significant, $F(1, 194) = .51$, $p = .48$, $\eta_p^2 = .003$. The non-significant main effect of FOV restriction does not mean that FOV restriction was ineffective compared

TABLE 1: Demographics and cybersickness by mitigation condition (no mitigation, FOV restriction only, snap turning only, and FOV restriction with snap turning) and gender. Means and standard deviations are provided for VIMSSQ, MSSQ, SSQ Total, ADS, final FMS, and exposure time (in minutes).

Mitigation	Gender	Count	VIMSSQ	MSSQ	SSQ-T	ADS	FMS	Time
None	Male	33	2.91 (2.35)	11.35 (15.38)	64.94 (50.24)	3.21 (2.36)	5.11 (3.20)	14.41 (5.52)
	Female	19	3.68 (2.50)	17.89 (17.54)	63.38 (35.40)	3.96 (1.83)	6.34 (2.61)	14.54 (5.02)
	Total	52	3.19 (2.41)	13.77 (16.35)	64.37 (45.02)	3.48 (2.19)	5.56 (3.03)	14.46 (5.29)
FOV	Male	36	2.89 (1.85)	9.51 (8.08)	37.71 (34.29)	2.13 (1.93)	3.46 (2.84)	17.88 (3.51)
	Female	20	4.75 (2.51)	17.58 (14.15)	59.47 (33.29)	3.53 (1.67)	5.70 (2.17)	14.53 (5.55)
	Total	56	3.55 (2.27)	12.17 (11.29)	45.48 (35.24)	2.63 (1.95)	4.26 (2.82)	16.69 (4.59
Snap	Male	29	2.69 (2.35)	8.78 (8.95)	24.50 (19.86)	1.49 (1.47)	2.78 (2.57)	19.31 (2.35)
	Female	23	4.35 (2.31)	13.43 (11.55)	45.37 (35.31)	2.42 (1.81)	4.15 (2.79)	17.84 (3.83)
	Total	52	3.42 (2.45)	10.84 (10.34)	33.73 (29.39)	1.90 (1.68)	3.38 (2.73)	18.66 (3.15)
Both	Male	20	3.90 (2.63)	12.06 (13.37)	49.56 (40.37)	2.53 (2.08)	4.40 (3.20)	17.51 (4.67)
	Female	21	4.81 (2.84)	16.74 (18.90)	66.25 (42.76)	2.74 (1.69)	5.07 (2.90)	17.41 (4.15)
	Total	41	4.37 (2.75)	14.46 (16.41)	58.11 (41.95)	2.64 (1.87)	4.74 (3.03)	17.46 (4.36)

TABLE 2: Correlations, means, and standard deviations for key demographic measures and cybersickness measures.

	1.	2.	3.	4.	5.	*M*	*SD*
1. Gender	—					—	—
2. VIMSSQ	-.28**	—				3.60	2.47
3. MSSQ	-.22**	.44**	—			12.71	13.65
4. Game hrs/wk	.40**	-.28**	-.19**	—		20.78	22.90
5. ADS	-.19**	.25**	.25**	-0.07	—	2.66	2.00
6. SSQ total	-.18**	.33**	.31**	-0.05	.58**	49.90	39.65

to no mitigation. Figure 2 shows that ADS was at least numerically lower with FOV restriction only compared to no mitigation, and this specific comparison is statistically evaluated below. However, ADS was numerically higher with FOV restriction and snap turning combined compared to snap turning only. These patterns led to a non-significant main effect of FOV restriction but a significant interaction between the two mitigation tools. Covariates VIMSSQ, $F(1, 194) = 5.88$, $p = .016$, $\eta_p^2 = .029$, and gender, $F(1, 194) = 3.97$, $p = .048$, $\eta_p^2 = .020$, were significant, but MSSQ was not, $F(1, 194) = 2.69$, $p = .103$, $\eta_p^2 = .014$.

Follow-up tests evaluated the prediction that the no mitigation condition would lead to greater cybersickness compared to the other three conditions, and that the combined mitigation condition would lead to lower cybersickness compared to the individual mitigation conditions. These tests were conducted as ANCOVAs comparing relevant condition pairs. Gender, VIMSSQ, and MSSQ were included as covariates. No mitigation led to significantly higher ADS than FOV restriction only, $F(1, 103) = 6.34$, $p = .013$, $\eta_p^2 = .058$, significantly higher ADS than snap turn only, $F(1, 99) = 22.18$, $p < .001$, $\eta_p^2 = .183$, and significantly higher ADS than both FOV restriction and snap turn together, $F(1, 88) = 6.17$, $p = .015$, $\eta_p^2 = .065$. The condition with both FOV restriction and snap turning combined was no different than FOV restriction only, $F(1, 92) = .12$, $p = .728$, $\eta_p^2 = .001$, nor snap turning only, $F(1, 88) = 2.75$, $p = .101$, $\eta_p^2 = .030$.

5.2 SSQ

The SSQ was administered before and after exposure to VR. However, pre-exposure scores largely indicated no symptoms and analysis of difference scores (post-minus-pre) produced conclusions that were identical to those based on post-exposure data only. Therefore, only post-exposure SSQ data are reported here. SSQ sub-scores (nausea, oculomotor, and disorientation) and total score were calculated using the recommendations from the original paper [2].

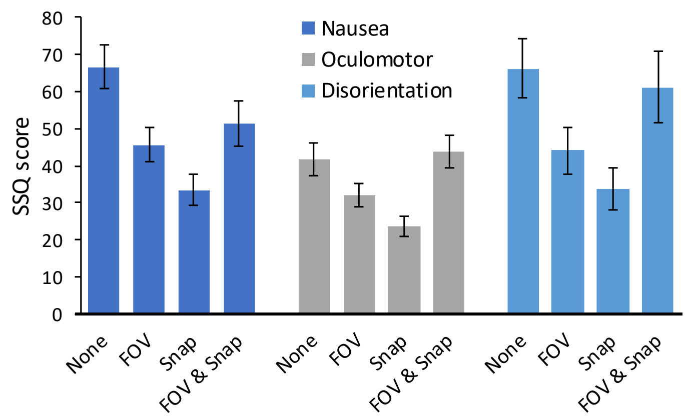

Fig. 3: Mean SSQ sub-scores (nausea, oculomotor, and disorientation) as a function of condition (no mitigation, FOV restriction only, snap turning only, and FOV restriction with snap turning). Error bars represent +/- 1 SEM.

Visual inspection of the data indicated similar SSQ sub-score profiles in each condition (See Figure 3). Therefore, statistical analyses were conducted using the SSQ total score. Separate analysis of each SSQ sub-score is reported on the Open Science Framework [39].

SSQ data were somewhat skewed (0.91) so a log transformation was applied [41]. The result was a more normal distribution with minimal skewness and more similar variances across conditions compared to the untransformed data. The homogeneity of variances assumption was met, $F(3, 197) = 0.85$, $p = .470$, so analysis proceeded with parametric tests. Analyses were conducted using the log-transformed data, but the figures present untransformed data for ease of interpretation. Equivalent figures showing

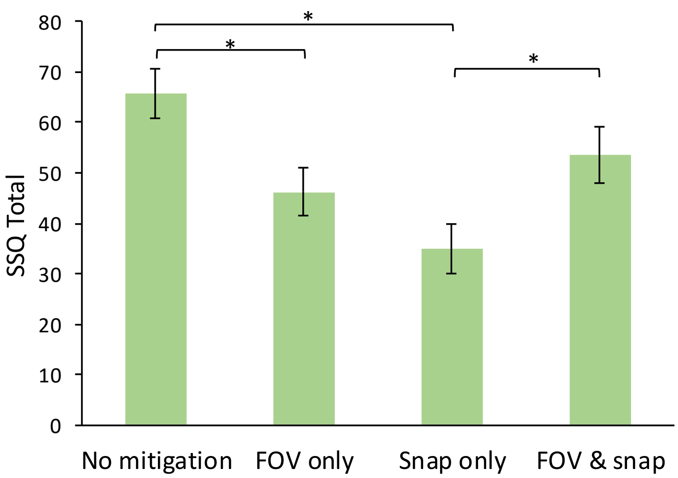

Fig. 4: Mean SSQ total scores as a function of condition. Error bars represent +/- 1 SEM. Asterisks indicate a statistically significant difference between conditions.

log-transformed data can be found on the Open Science Framework [39].

A 2 (FOV restriction) × 2 (snap turning) ANCOVA was conducted with SSQ total as the dependent variable and gender, VIMSSQ, and MSSQ as covariates. Estimated marginal means for each of the four conditions are displayed in Figure 4. The main effect of snap turning was significant, $F(1, 194) = 5.93$, $p = .016$, $\eta_p^2 = .030$, and the interaction between FOV restriction and snap turning was significant, $F(1, 194) = 13.23$, $p < .001$, $\eta_p^2 = .064$. The main effect of FOV restriction was not significant, $F(1, 194) = .00$, $p = .992$, $\eta_p^2 = .000$. The non-significant main effect of FOV restriction does not mean that FOV restriction was ineffective compared to no mitigation. Figure 4 shows that SSQ total was at least numerically lower with FOV restriction only compared to no mitigation, and this specific comparison is statistically evaluated below. However, SSQ was numerically higher with FOV restriction and snap turning combined compared to snap turning only. These patterns led to a non-significant main effect of FOV restriction but a significant interaction between the two mitigation tools. Covariates VIMSSQ, $F(1, 194) = 14.00$, $p < .001$, $\eta_p^2 = .067$, and MSSQ, $F(1, 194) = 8.12$, $p = .005$, $\eta_p^2 = .041$, were significant. Covariate gender was not significant, $F(1, 194) = 3.19$, $p = .076$, $\eta_p^2 = .016$.

Follow-up tests evaluated the prediction that the no mitigation condition would lead to greater cybersickness compared to the other three conditions, and that the combined mitigation condition would lead to lower cybersickness compared to the individual mitigation conditions. These tests were conducted as ANCOVAs comparing relevant condition pairs. Gender, VIMSSQ, and MSSQ were included as covariates. No mitigation led to significantly greater cybersickness than FOV restriction only, $F(1, 103) = 6.43$, $p = .013$, $\eta_p^2 = .059$, and significantly greater cybersickness than snap turn only, $F(1, 99) = 20.40$, $p < .001$, $\eta_p^2 = .171$. There was no difference between the condition with no mitigation and the condition with both FOV restriction and snap turning, $F(1, 88) = 2.18$, $p = .143$, $\eta_p^2 = .024$, nor was there a difference between FOV restriction only and FOV restriction with snap turning, $F(1, 92) = .64$, $p = .425$, $\eta_p^2 = .007$. The condition with both FOV restriction and snap turning actually led to significantly *greater* cybersickness than snap turning only, $F(1, 88) = 6.68$, $p = .011$, $\eta_p^2 = .071$.

TABLE 3: Means and standard deviations for selected items from the VRNQ scale, reflecting subjective user experience. Values are reported separately by cybersickness mitigation condition (no mitigation, FOV restriction only, snap turning only, and FOV restriction with snap turning).

Mitigation	Immersion	Enjoyment	Graphics	Navigation
None	4.82 (1.13)	4.27 (1.39)	4.33 (1.44)	4.90 (1.02)
FOV	4.39 (1.27)	4.36 (1.31)	4.63 (1.26)	5.21 (1.16)
Snap	4.58 (1.09)	5.04 (1.14)	4.61 (1.18)	5.04 (0.91)
Both	4.22 (1.08)	4.44 (1.18)	4.29 (1.05)	4.72 (1.15)

5.3 Subjective experience

The VRNQ included a number of 7-point usability questions, including measures of enjoyment and ease of use. The focus in this section is on items that seem likely to be influenced by field of view restriction and snap turning. Specifically, immersion, enjoyment, graphics quality, and ease of navigation are presented here due to their potential relationship with cybersickness mitigation tools. Those items are presented in Table 3, and the full table is available on the Open Science Framework [39].

Each item of interest was analyzed in an ANOVA with condition as the independent variable. Follow-up contrasts are reported where the ANOVA was significant. The ANOVA testing immersion ratings was marginally significant, $F(3, 197) = 2.38$, $p = .071$, $\eta_p^2 = .035$. Immersion was higher with no mitigation compared to FOV restriction only ($p = .05$) and with both FOV restriction and snap turning combined ($p = .013$), and did not differ between other conditions.

The ANOVA testing enjoyment ratings was statistically significant, $F(3, 197) = 3.96$, $p = .009$, $\eta_p^2 = .057$. Enjoyment was higher in the snap turning condition compared to all other conditions ($p \leq .015$), which did not differ from one another. Given that enjoyment is likely related to cybersickness, and that cybersickness is affected by condition, we also conducted the ANOVA including ADS as a covariate. In this case, the effect of condition was not significant, $F(3, 196) = 2.07$, $p = .106$, $\eta_p^2 = .031$.

The ANOVA testing graphics quality ratings was not significant, $F(3, 196) = 0.99$, $p = .398$, $\eta_p^2 = .015$, so no further follow-up tests were conducted. The ANOVA testing ease of navigation was marginally significant, $F(3, 194) = 1.85$, $p = .140$, $\eta_p^2 = .028$, so no further follow-up tests were conducted due to the lack of clear hypotheses and relatively large number of tests on VRNQ data.

6 Discussion

Field of view restriction and snap turning both independently reduced cybersickness when playing a VR game compared to a no mitigation control condition. Yet, the two mitigation techniques combined did not further reduce cybersickness beyond each individual mitigation technique alone. Combining FOV restriction and snap turning actually led to increased sickness (numerically greater ADS, statistically greater SSQ) compared to snap turning only.

The finding that FOV restriction alone led to lower sickness than no mitigation adds to a growing body of work showing the effectiveness of FOV restriction for mitigating cybersickness [15], [16], [17], [18], [19], [20], [21], [42]. Further, the finding that snap turning alone led to lower sickness than no mitigation adds clarity to the discrepant findings reported by two prior studies on snap turning [22], [23]. It is possible that the study in which snap turning did not reduce cybersickness [23] suffered from floor effects, whereby cybersickness was too low in the smooth rotation control condition to detect a significant benefit of snap turning. On the other hand, smooth rotation in that study did result in significant cybersickness compared to baseline (i.e., relative to pre-exposure ratings), so significant cybersickness did occur. Perhaps other variables that may have differed across studies (e.g., snap turn angle, timing of the transition between viewpoints, or insertion of a blank screen between views) affect cybersickness and warrant further research attention.

It is puzzling that snap turning and FOV restriction combined did not reduce cybersickness beyond either mitigation tool alone. In fact, cybersickness as measured by the SSQ was higher when both tools were combined than when snap turning was used alone. This pattern was also found in ratings of enjoyment, although that finding may have been driven by differences in cybersickness across condition.

The lack of added benefit when FOV restriction and snap turning were combined was not likely caused by a floor effect in cybersickness ratings. The mean SSQ score of 33.7 with snap turn only is still non-negligible, leaving ample room for improvement. Sampling error (i.e., differences in participant characteristics across groups due to randomness in recruiting) is also not a likely explanation. Not only are the sample sizes healthy, but the analyses also controlled for participant demographics (gender, history of motion sickness, and history of VIMS) that were related to cybersickness. It is possible, therefore, that some cybersickness mitigation tools simply do not combine in their mitigating effects.

Responses to questions about subjective experiences in VR indicated that immersion was highest when no mitigation tools were used compared to either FOV restriction or snap turning. It makes sense that reducing field of view or blocking intermediate views during rotation led to lower immersion ratings, and this finding parallels prior reports of lower presence (i.e., the illusion of being there [43]) when FOV is reduced [19]. Although one study found no effect of FOV restriction on presence [16], the amount of FOV restriction in that study was less than what was used in the current study. Therefore, magnitude of FOV reduction might moderate the effect of FOV reduction on immersion.

Enjoyment ratings were highest in the snap turning condition. This finding was most likely due to the lower cybersickness experienced in that condition, which corresponded to greater enjoyment of the game. It is no surprise that users find cybersickness unenjoyable (ADS was negatively correlated with enjoyment ratings, r = -.328), and differences in enjoyment across conditions were eliminated when cybersickness was controlled for.

6.1 Limitations and future directions

One important limitation of the current work is that the conditions were not designed to directly compare the effectiveness of FOV restriction and snap turning as cybersickness mitigation techniques. Rather, the goals were to evaluate the effect of combining multiple cybersickness mitigation tools, and to verify the effectiveness of each tool individually. Although snap turning led to numerically less cybersickness than FOV restriction, these mitigation tools were not equated in any meaningful way beyond pilot testing to ensure moderate reduction in cybersickness. Further restriction in FOV might lead to cybersickness levels similar to that achieved with snap turning. Likewise, snap turning parameters such as the angle of rotation or the transition between viewpoints (e.g., timing, or fading between views) might also affect cybersickness. A more meaningful comparison of the two mitigation tools could involve a broader sampling of the variables that might influence each tool's effectiveness. For example, a study that manipulates the magnitude of FOV restriction along with the magnitude of the rotational snap would be better positioned to compare the effectiveness of the two mitigation tools.

Another limitation is that there are many implementations of FOV restriction that were not tested in this study. FOV restriction in the current study occurred almost instantly and in an all-or-nothing manner (i.e., there was no intermediate amount of FOV restriction when traveling at intermediate speed). In contrast, others have used dynamic FOV restriction that is linked to travel speed [21], [44] or linked to eye gaze [18], both of which also appear quite effective at reducing cybersickness. It is possible that other implementations of FOV restriction would interact differently with snap turning, although there is no a priori reason to expect this.

Cybersickness researchers have historically applied FOV restriction during both translation and rotation [16], [18], [21]. In the current study, FOV restriction only occurred during translation. It is unknown whether added benefits will occur when FOV restriction is applied during rotation. Although it seems logical that FOV restriction during rotation would further reduce cybersickness, the current study shows that mitigation tools may not combine in logical ways. Due to the negative effect of FOV restriction on immersion, its usage should be based on scientific evidence that it further reduces cybersickness. Therefore, future research on FOV restriction should separately consider the impacts of FOV reduction during translation and rotation.

Finally, the conclusion that multiple cybersickness mitigation tools do not combine to further reduce cybersickness may not generalize beyond the two mitigation tools used here. Examples of other approaches to mitigating cybersickness (many of which are implemented in GingerVR [15]) include rest frames that provide a stable visual reference frame [45], [46], [47], [48], teleportation when translating (i.e., changing position) [25], [29], [49], [50], visual dots that move in the opposite direction to cancel out visual motion [51], foveated depth-of-field blur [52], and foveated rendering [53]. Future research should examine whether the current findings extend to other cybersickness mitigation tools that are easily or commonly paired.

7 Conclusions

FOV restriction and snap turning were both found to be effective cybersickness mitigation tools when used independently. However, the two mitigation tools in combination were no more effective, and in some cases less effective, than when presented in isolation. Given the potential cost of some mitigation tools on user experience, it is recommended that they not be combined without evidence that doing so comes at an advantage in cybersickness mitigation.

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