Can Gender and Motion Sickness Susceptibility Predict Cybersickness in VR ?

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ABSTRACT

VR headsets are becoming part of our everyday lives, however, cybersickness is a common side effect when using these devices. The experience and intensity of symptoms varies greatly between individuals with some seemingly resistant to cybersickness and other suffering greatly. It is still not clear why some individuals suffer more than others and what characteristics might contribute to such a resistance. In this study, we investigate two individual characteristics that have been commonly discussed in relation to cybersickness with no clear consensus being established so far: gender and motion sickness history. Findings support the notion that females are more susceptible to motion sickness. However, one's motion sickness history did not relate to symptoms of cybersickness. In line with this, the difference in motion sickness history between genders did not translate to their experience of cybersickness, with males and females experiencing similar levels of cybersickness. These findings demonstrate the complexity of the relationship between gender and motion sickness history and their impacts on the experience of cybersickness. This work highlights the need for future exploration of individual characteristics and their effects on cybersickness susceptibility.

Keywords: Cybersickness, individual differences, Gender, Motion Sickness History

Index Terms: Human-centered computing—Human Computer interaction—Empirical studies in HCI

1 INTRODUCTION

Virtual Reality (VR) headsets have made their way into mainstream gaming, the educational and health sectors, and have more recently been introduced as productivity and entertainment tools for cars and other types of transport [34]. However, their usage can lead to adverse motion sickness like symptoms (referred to as cybersickness), such as headaches, nausea, dizziness and eye strain [23]. The experience and intensity of these symptoms seems to be strongly impacted by individual differences, to the extent that some individuals are unable to use VR headsets at all as they experience severe cybersickness, thereby, potentially limiting the wider uptake, and the commercial success of VR applications. Two individual characteristics often discussed as being related to or even as potential predictors of someones experience of cybersickness are gender and motion sickness history.

Most research suggests that females experience more cybersickness than males [30, 36, 42] and that history of traditional motion sickness (experience in cars, busses, fun rides, etc.) can predict experience of cybersickness when using VR headsets. However, for both of these claims there is also research failing to find support or even suggesting alternative explanations for such findings [2, 19, 32]. It has been argued that the gender differences found for cybersickness could be explained by an individual's susceptibility to motion sickness, with individuals that are more susceptible to motion sickness in the real-world experiencing more discomfort in virtual environments, independent of their gender [19].

In this study, we examine how individual differences, in particular gender and motion sickness history relate to cybersickness in VR-naïve participants. Of particular interest for us was whether motion sickness history could be a main contributor to gender differences found for cybersickness. We propose the following research questions:

- **R1**: Does gender affect the experience of cybersickness in VR?
- **R2**: Are there differences in motion sickness susceptibility between genders?
- **R3**: Can an individual's motion sickness history predict their experience of cybersickness?

2 BACKGROUND

Individual differences in the experience of cybersickness, with some individuals being more susceptible than others, are a common finding in research and anecdotal observations. In this section, we focus on two individual characteristics that are often discussed as possible predictors of cybersickness: gender and motion sickness history.

2.1 Gender Differences

Females are believed to be more susceptible to motion sickness like symptoms and discomfort experienced in real-life scenarios, such as travelling on a bus [45] or by sea [30], in driving simulators [7,15,40] as well as when navigating through virtual environments presented using Head mounted displays (HMDs) [9, 36, 42]). This suggests that females are more susceptible to motion sickness both when sensory inputs are congruent (real life situations) and incongruent (virtual environments). Various hypotheses have been proposed for this difference.

Gender differences in the control of postural stability could be one cause [28]. Postural stability has been linked to motion sickness in the past, with individuals that experience more sway also experiencing more motion sickness [5, 8, 43]. Females have often been shown to sway more and have less postural stability compared to males [13] which could contribute to their stronger experience of cybersickness symptoms. Additionally, females generally have a wider field-of-view (FOV), possibly resulting in a sensory experience that differs from that of males [27, 29]. Optic flow presented in a wider FOV generally elicits stronger sensations of cybersickness [11, 31], which is supported by the success in reducing cybersickness in HMDs using FOV restrictors [1, 44, 49]. This suggests that males, due to their smaller FOV, may be predisposed to experience less cybersickness compared to females. There also seems to be more variability in motion sickness susceptibility over time for females compared to males. Females susceptibility to motion sickness has been found to

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fluctuate through their menstrual cycle [18], with hormones within many oral contraceptives possibly further affecting these changes in susceptibility [33]. Similarly Cortisol levels that change throughout the day seem to affect the experience of motion sickness in females but not males [35]. This suggest that for females more than for males both the time of the day as well as the day of their cycle could strongly affect their experience of cybersickness and thereby potentially skew study results.

Further, cybersickness is most commonly measured using self-report scales. Differences in experience between genders could be males being reticent to report adverse symptoms, rather than an actual difference in their sensory response [4].

However, some studies were unable to find any effects of gender on cybersickness [2, 32]. While research investigating the effect of motion sickness susceptibility or an individual's motion sickness history, found that, when susceptibility was kept constant between males and females, no difference in cybersickness was found between genders [19]. Females in general also tend to report being more susceptible to motion sickness, which in turn is said to relate to the experience of cybersickness in VR studies [42].

2.2 Motion Sickness History

An individual's motion sickness history has previously been found to be a good predictor of cybersickness [39, 42, 46, 48], with individuals that report more occurrences of motion sickness in real-world scenarios, such as riding in a bus, train or car or on fun rides, also experiencing stronger symptoms of cybersickness when immersed in VR. Most research examining cybersickness, therefore, includes a measure of motion sickness susceptibility or motion sickness history, such as the Motion Sickness Susceptibility Questionnaire (MSSQ; [16]) or the Motion Sickness History Questionnaire (MHQ; [20]).

Based on current literature, it is unclear whether there is a difference in the experience of cybersickness between genders or whether this difference could be explained by an individual's susceptibility to motion sickness rather than their gender. Our study explores this relationship further by investigating differences in susceptibility to motion sickness between genders and by investigating how these two characteristics relate to cybersickness.

3 Methods

3.1 Participants

Thirty-two participants took part in this study. They were recruited through an internal recruitment system as well as various social media channels. Each participant received £10 for completing the study. Three participants terminated the experiment early due to high cybersickness symptoms - their data were not excluded from the analyses but rather their last recorded FMS score was reported for the remainder of the condition [12]. Seventeen participants identified as male, 13 as female and 2 as gender non-binary. Data from two participants identifying as gender non-binary were excluded from the analyses due to not enough data points being available to include this third gender group. Participants were given the following options for gender identity on the pre experiment questionnaire: *male, female, trans*, agender, gender non-binary, intersex*, "prefer not to say" or they had the option to write down their gender if it was not listed. The final sample ranged in age from 18 to 34 years (M = 25.17, SD = 3.73). Fifteen of those had never used VR before and the remaining 17 had used it between 1-10 times. Nine males and six females had such limited prior VR experience. A two-sample test for equality of proportion found that there was no significant difference in prior VR experience between males and females (χ^2(1, N=30)= 0, p = 1).

3.2 Measures

The measures used for the analyses in this paper were recorded in a pre-screening interview to determine an individual's motion sickness history and gender, and throughout the VR task to measure experienced cybersickness.

Figure 1: Example of participant set up

Gender Participants reported the gender they identified as prior to taking part in the experiment

Motion Sickness History The Motion Sickness Susceptibility Questionnaire Short Version (MSSQ-Short; [16]) was administered before the experiment to assesses participants' susceptibility to motion sickness and their motion sickness history.

Cybersickness Participants filled in the Fast Motion Sickness Scale (FMS; [22]) five times while immersed in the virtual task (every 4 minutes) as a measure of cybersickness. The experiment was terminated if participants reached a score of 11 or higher, to prevent participants from becoming too unwell.

3.3 Study Design and Procedure

The study used a between subjects design with cybersickness level as dependent variable and gender as independent variable. Additionally, the relationship between motion sickness history and cybersickness was investigated. The experiment consisted of one experimental session in which participants were immersed in a virtual environment eliciting a sensation of self-forward motion (vection). This environment was displayed to participants using the Meta Quest 2 headset (see Figure 1). Participants travelled through an abstract tunnel that mainly involved the perception of motion in depth. This tunnel travel task was adapted from [3], which is a well-established gamified paradigm for the assessment of multitasking cognitive control abilities, such as visuomotor tracking ability and visual discrimination ability (see Figure 2). The route within the tunnel enacts normal VR locomotion, including curves, uphill and downhill paths, but without upside down and off-axis paths. While exposed to this passive locomotion, participants had to perform two cognitive tasks: a visuomotor tracking task that was part of the tunnel environment, they had to track and control a white and black game object to hit the centre of the cubes in the tunnel as accurately as possible by moving the right thumbstick on the VR controller. The second task was a visual discrimination task presented on a virtual screen in the centre of the participant's field of view. A stream of different coloured

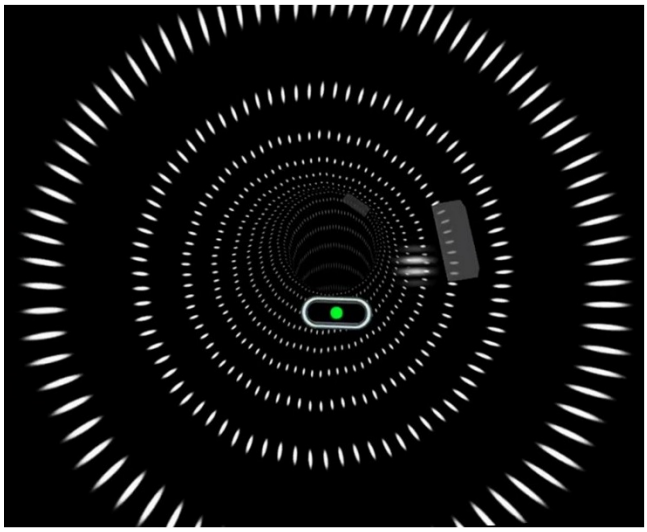

Figure 2: Example of the tunnel travel task including the visuomotor tracking task and visual discrimination task.

(red, green, blue) shapes (circle, pentagon, square) was presented with the target (green circle) appearing every 2-3 seconds. They had to respond to the target as quickly as possible by pressing the left trigger while ignoring all non-target distractors.

Participants went through a training phase lasting 4 minutes to familiarise themselves with the controls and tasks followed by the main task. The tunnel travel task lasted 20 minutes in total, divided into 5 sessions lasting 4 minutes each. After each session, participants rated their experience of cybersickness on the FMS, resulting in 5 ratings per participant. Unlike the fixed movement speed in the original version of [6], the movement speed was increased in a linear fashion with each session (every 4 minutes) to increase task difficulty and the sickness inducing properties of the environment [10, 41]

4 Results

4.1 Motion Sickness History

4.1.1 Gender Differences

A Kruskal Wallis one way analysis of variance found a significant main effect of gender for motion sickness susceptibility (χ^2(1, N=30)= 6.37, p = .012, η^2 = .19), with females reporting a stronger history of motion sickness (M = 14.07, SD = 10.45) compared to their male counterparts (M = 5.45, SD = 8.64). See Figure 3.

4.1.2 Relationship with Cybersickness

Spearman correlations were conducted to investigate the relationship between motion sickness history (MSSQ scores) and experience of cybersickness (FMS ratings) on the average FMS scores and the maximum FMS scores. No significant relationship between MSSQ scores and average FMS ratings, (rs(28) = .33, p = .074) or maximum FMS (rs(28) = .27, p = .146) ratings was found, suggesting that a person's previous experience of motion sickness does not relate to their experience of cybersickness.

4.2 Gender as Predictor of Cybersickness

Kruskal Wallis one way analyses of variance found no significant main effect of gender on average FMS ratings (χ^2(1, N=30)= 1.70, p = .193, η^2 = .03) and maximum FMS ratings (χ^2(1, N=30)= 1.46, p = .228, η^2 = .02), with females experiencing the same amount of adverse symptoms (average: M = 2.66, SD = 2.95; maximum: M = 4.23, SD = 3.77) compared to their male counterparts (average: M = 1.86, SD = 2.55; maximum: M = 4.23, SD = 3.77). See maximum FMS scores in Figure 4.

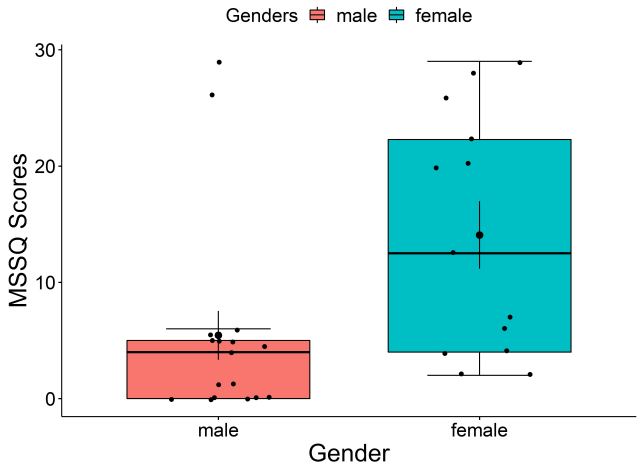

Figure 3: MSSQ scores for gender groups. Thick middle lines represent the median and the colour of the boxes represent the gender of participants. Male: red, female: blue.

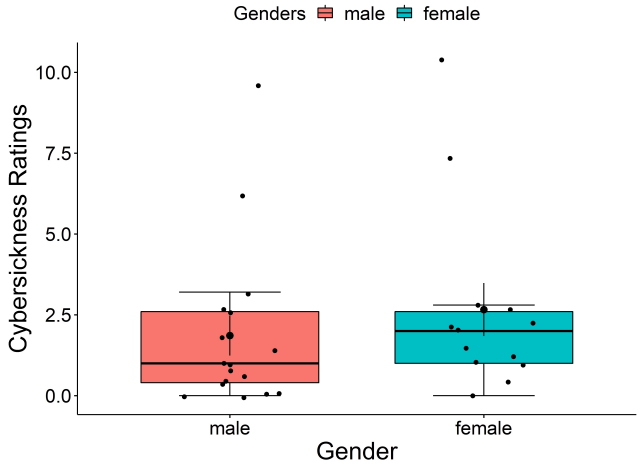

Figure 4: Maximum FMS scores for gender groups. Thick middle lines represent the median and the colour of the boxes represent the gender of the participants. Male: red, female: blue.

4.2.1 Cybersickness Development over Time

A linear mixed model analysis was performed to investigate the effect of gender and time (Round) on cybersickness. This analysis again found no significant effect of gender on FMS ratings (F (1,28) = 0.64, p = .432) or of the interaction between gender and number of rounds (F (4,112) = 2.07, p = .089). However, a significant effect of time/round number was found on FMS ratings (F (4, 112) = 5.98, p ¡ .001). Post Hoc analysis revealed significant differences in FMS ratings between *Round One* (M = 1.43, SD = 2.10) and *Round Four* (M = 2.80, SD = 3.76, t(112)= 3.52, p = .006) as well as *Round Five* (M = 2.83, SD = 3.53, t(112)= 3.72, p = .003). As well as significant differences between *Round Two* (M = 1.60, SD = 2.27) and *Round Four* (t(112)= 3.10, p = .020) as well as *Round Five* (t(112)= 3.30, p = .011). *Round Three* (M = 2.37, SD = 3.32) did not differ significantly from any of the other rounds.

5 Discussion

Our findings support previous work suggesting that females are more susceptible to motion sickness (R2) and rate their motion sickness as more severe compared to males. Motion sickness history, however, did not relate to the severity of cybersickness symptoms experienced in the VR experiment (R3). In line with this, we found no difference in cybersickness ratings between male and female participants (R1). Therefore, even though females had a stronger history of motion sickness in the real world, they did not experience stronger sensations of cybersickness when compared to their less motion sickness susceptible male counterparts.

5.1 Motion Sickness History does not Predict Cybersickness

The findings of this work contradict the consensus of most of the previous published work. Motion sickness history in the real world experienced on different types of transport (buses, cars, ships) and fun rides (roller coasters) did not relate to cybersickness experienced in VR. However, the findings are in-line with the authors experiences from prior conducted research that motivated this formal study. The question is why does motion sickness history in some cases predict sickness experienced in virtual environments and in other does not? One of our theories is that high motion sickness susceptibility could be a predictor of cybersickness while motion sickness resistance does not imply cybersickness resistance. For example an individual that has a strong history of traditional motion sickness in the real world is very likely to experience cybersickness in VR. However, resistance to motion sickness in the real world does not translate into cybersickness resistance, someone that never experiences traditional motion sickness, such as car or seasickness can still be susceptible to cybersickness. This could be due to a difference in the strain put on the vestibular system when experiencing cybersickness (purely visually induced motion sickness) and motion sickness in the real world that includes both physical and visual motion. Some individuals could have an overly sensitive reaction to any sensory motion input, some could be overly sensitive to vestibular input and mismatch and others could have an overly sensitive reaction to primarily visual input and mismatch.

The MSSQ scores reported by our participants were below average for males and around average for females [17], which would suggest that our cohort in general reported a rather low history of motion sickness, which in turn could explain why the ratings did not relate to the adverse symptoms they experienced in our VR task.

As mentioned above, participants overall scores of cybersickness were rather low, which could suggest that participants did not experience *enough* cybersickness for the correlation analyses to be evaluated and result in a clear resolution. To further investigate the notion that motion sickness history and cybersickness are unrelated, a VR experiment that elicits a stronger experience of cybersickness should be conducted. Such an experiment could also include individuals with varying degrees motion sickness history to test the hypothesis that a strong history of motion sickness is a good predictor of cybersickness as sugggested above.

Various researchers have proposed alternative questionnaires to determine an individuals susceptibility to cybersickness, such as the Cybersickness Susceptibility Questionnaire (CSSQ, [14]), the Visually Induced Motion Sickness Susceptibility Questionnaire (VIMSSQ, [24]) and the Virtual Reality Sickness Questionnaire (VRSQ, [25]). These questionnaires are based on the aspect that for cybersickness in contrast to traditional motion sickness, physical movement is typically missing and symptoms are primarily caused by stimulation of the visual system, resulting in a different pattern of symptomatology. None of these proposed questionnaires however are as widely used and accepted as the MSSQ, with most cybersickness researchers still including the MSSQ in their studies rather than these more specific questionnaires.

5.2 Females and Males Experience Cybersickness Similarly

Even though our female participants had a stronger history of motion sickness compared to males no difference in their experience of cybersickness was found when performing our tunnel travel-task. This contradicts most previous research suggesting that VR is less accessible to females due to their susceptibility to cybersickness [9, 36, 38, 42].

Previous work that has also failed to report this gender difference contributed these null results to the low levels of adverse symptoms experienced in the virtual environment [26, 36], which would suggest that the severity of cybersickness symptoms could have an impact on this gender biases in cybersickness, with differences only occurring for environments inducing strong sensations of cybersickness. The tunnel travel-task elicits a weak or moderate experience of cybersickness symptoms in most participants, which would be expected to be equivalent to a standard walking-pace consumer VR game. This could partially explain why no difference was found between male and female participants here. Gender could have potentially little to no effect on the severity of symptoms when little to no cybersickness is occurring, but might play a bigger role when the symptoms are more extreme.

This discrepancy in findings brings up the question whether it is really an individual's gender that determines their susceptibility to cybersickness or if it is other individual characteristics that are the cause of this biases found in some work. Motion sickness history has previously been proposed as the cause between these differences with females often reporting higher motion sickness susceptibility which rather than their gender is the cause of higher ratings of discomfort when exposed to virtual environments [19]. Our work, however, somewhat contradicts this notion, with our more motion sickness susceptible female participants experiencing similar levels of cybersickness compared to our less motion sickness susceptible males.

Time spent playing video games has also been shown to impact users susceptibility to cybersickness, with individuals that classify as gamers, someone that has spend extensive time playing video games in the past, often experiencing weaker and less sickness symptoms when immersed in HMDs or other more sickness inducing virtual environments (e.g., driving simulators, etc.) [21, 37, 38, 47]. These beneficial effects have been found for both male and female participants with some work [38] even suggesting that these effects might be more pronounced for females rather than males. This further highlights the need for future work to answer the question whether gender difference for cyebrsickness really existent or whether they are influenced by other individual characteristics and not gender itself.

5.3 Limitations

Our work only included participants identifying as either female or male due to the small number of participants identifying as gender non-binary, meaning their data had to be excluded from this experiment. This hints towards one of the potentially main limitations of this study. When discussing differences in motion sickness and cybersickness for females and males the causes of such difference are often based on potential sex difference (wider FOV, hormonal differences, postural instability) [27–29] rather than gender differences. Most studies, however, only report the gender rather than the sex of their participants with most studies in the past only focusing on male and female participants. It is unclear whether sex differences and gender difference are the same when it comes to motion sickness susceptibility or if a differentiation has to be made here. In line with this if gender is believed to affect motion sickness more inclusive studies have to be conducted in the future that either include more categories of gender (gender non-binary, agender, etc.) or potentially treat gender as a continuous rather than a categorical variable.

In our work we included these gender "categories" in our survey, however did not find enough participants identifying as neither female or male to include these groups in further analyses. Future work should ensure that participants representing a broader field of gender identities are included. Alternatively or in conjunction with this, future work could ask participants to report both their sex (assigned at birth) and gender allowing to investigate any existing differences between these. A further limitation is the unbalanced gender contribution of our sample , with 17 male and only 13 female participants.

The cybersickness ratings reported for the analysis in this paper are based on the average and maximum FMS ratings of each participant reported throughout the experiment. They reported their level of cybersickness every 4 minutes during a quick break from the task resulting in 5 cybersickness ratings overall. This only provides partial information about users experience of cybersickness and does not allow us to gather any detailed information about the time course or the exact onset of cybersickness. To allow for this a continuous rating scale could be included in the experiment allowing participants to change their ratings at any time.

5.4 Implication for Future Research and VR Developers

The findings of this study highlight the need for future work investigating individual characteristics that relate to cybersickness susceptibility, with no clear consensus being found so far. Such work can give clear guidelines as to what participant demographics researchers should report and how these could influence the outcome of cybersickness research.

Additionally, such work could provide guidelines for VR developers, depending on what demographic their application is aimed at they could adapt their virtual worlds to include more or less cybersickness mitigation techniques, such as FOV restrictors or include more or less sickness inducing locomotion techniques. This work could also form the basis of research investigating whether individual differences affect the effectiveness of different cybersickness mitigation strategies, for example FOV restrictors could be more effective for females compared to males or vice versa. All of this knowledge can ultimately help us to find a way to make VR accessible for everyone and help more people build up resistance to cybersickness.

6 Conclusion

This study found that neither one's gender nor one's motion sickness history is able to predict the severity of cybersickness symptoms experienced in a virtual tunnel travel-task. Even though females had a stronger history of traditional motion sickness they did not experience significantly more cybersickness compared to males. These findings further highlight the complex interplay of individual characteristics and how they could predict susceptibility to cybersickness. The aim of the motion sickness research community is to make VR accessible for everyone and ideally eliminate cybersickness experienced when immersed in all types of virtual applications. To achieve this goal future work needs to focus on what individual characteristics determine who is cybersickness resistant and who will suffer severe symptoms when using VR headsets.

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