*Human Factors in Virtual Environments and Game Design,* Vol. 137, 2024, 95–106
https://doi.org/10.54941/ahfe1004991

# A Survey on the Relationship Between Stress, Cognitive Load, and Movement on Cybersickness

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## ABSTRACT

This survey focuses on a crucial virtual reality (VR) issue that has been reported to affect roughly 40% of VR users – cybersickness. Cybersickness is similar to motion sickness but occurs with electronic screens or VR displays instead of actual movement. Cybersickness can refer to a cluster of symptoms, including nausea, eye strain, vertigo, and sweating, to name a few. Within training exercises using VR for law enforcement, we have anecdotally seen that more than 40% of our trainees report some symptom of cybersickness. Our training scenarios often include stressful and mentally charged situations, as well as include intense head and body movements for operational and tactical purposes. As such, this survey explores the scientific literature to see if there have been any reported links between stress, cognitive load, and head and body movement on reported cybersickness levels. A total of fourteen papers were surveyed. Findings were often mixed and inconclusive but pointed towards a positive relationship between cybersickness and both cognitive load and stress. On the other hand, studies looking at head movements showed a negative relationship with levels of cybersickness. It is hoped that these insights can help VR researchers develop new training protocols that can be more comfortable and accessible for all users.

**Keywords:** Cybersickness, Virtual reality, Stress, Cognitive load, Movements

## INTRODUCTION

The emergence of virtual reality (VR) as a cutting-edge technology has transformed several sectors, including education (Ding and Li, 2022), healthcare (Pillai and Mathew, 2019), and notably, law enforcement training (Hormann, 1995). The immersive nature of VR allows for the simulation of highly realistic and complex scenarios that would be difficult, dangerous, or impossible to replicate in real life (Giessing, 2021). This capability is particularly beneficial for training of law enforcement officers, where exposure to a wide range of high-risk situations in a controlled environment is crucial for effective learning and preparation (Zechner et al., 2023). However, the integration of VR into such critical training programs is not without its

 

challenges (Kleygrewe, 2023). Among these, cybersickness stands out as a significant barrier to the widespread adoption of VR technology (Stanney et al., 2020). Cybersickness, a condition related to motion sickness but induced by immersion in a virtual environment, manifests through a cluster of symptoms including nausea, dizziness, headache, and disorientation, to name a few (Caserman et al., 2021). Unlike traditional motion sickness, which results from physical movement, cybersickness is caused by the dissonance between visual motion cues and the lack of corresponding vestibular responses in a stationary user (Oman, 1990).

Recent studies have suggested that up to 60% of VR users (and in some cases up to 80% if involving fast-moving objects with low resolution screens) experience some form of cybersickness (Ahn et al., 2020; Kim et al., 2005). These statistics highlight the importance of addressing this issue to enhance the effectiveness of VR-based training. In fact, high-stress situations, such as those involving active shooter responses or high-speed chases, require a lot of attention and rapid response to process multiple data simultaneously, which imposes a significant stress and cognitive load on officers. These factors, when coupled with the necessity of doing rapid physical movements, can amplify the symptoms of cybersickness. The psycho-physiological factors contributing to cybersickness are numerous. The "butterfly in the stomach" phenomenon (Lai et al., 2023), a term for the anxiety-induced physiological response, serves as a metaphor for the complex interaction between stress, cognitive load, and physical responses in VR environments. This analogy emphasizes the hypothesis that stress and mental workload, integral to law enforcement training scenarios, may impact the intensity of cybersickness. Understanding these dynamics is essential for developing VR training programs that are not only effective but also physically and psychologically comfortable for participants, thus making them accessible to all.

## METHODOLOGY

Given the potential implications of cybersickness on the adoption and effectiveness of VR in law enforcement training, this survey paper seeks to explore the relationships between stress, cognitive load, and physical movement with cybersickness that have been published in the literature. To this end, we employed a search strategy to gather relevant studies using the following keywords:

- *virtual reality* AND
- (*cybersickness* OR *motion sickness*) AND
- *stress* OR (*cognitive load* OR *mental workload*) OR (*body movements* OR *head movements*).

The search spanned publications from 2000 to 2024 appearing in the following databases: Google Scholar, ScienceDirect, and PubMed. This exploration aims to fill gaps in understanding of how VR can be optimized for high risks training without compromising user comfort and performance. By examining these under-explored aspects of VR training, our study contributes to the challenge of improving the effectiveness and acceptability of VR as a transformative tool for training of law enforcement professionals.

## RESULTS

### Link Between Stress and Cybersickness

Stress is an important component of law enforcement training, where scenarios are designed to be as realistic and challenging as possible. This intentional stress stimulation aims to prepare officers for real-world situations. Stress can amplify the sensory conflict that leads to cybersickness, as the body's heightened state of arousal may intensify the discordance between visual cues and the absence of corresponding physical motion, potentially increasing symptoms such as the "butterfly in the stomach" feeling, which can compromise the efficacy of the training. It is important to note, however, that the causal relationship between stress and cybersickness is not definitively clear, with some studies suggesting that factors like high trait anxiety might contribute to both stress and cybersickness. Table 1 presents the five studies that investigated the correlation between stress and cybersickness symptoms.

**Table 1.** Studies examining the relationship between stress and cybersickness symptoms.

| Ref | Year | Results | Nb of Participants | Questionnaires |
|---|---|---|---|---|
| (Garrido et al., 2022) | 2022 | The results showed that steeper increasing trajectories of cybersickness could be found for those with greater susceptibility to physical stress and cognitive stress. | 92 | VRSQ, COPSOQ III, IPQ |
| (Stelling et al., 2021) | 2021 | High trait anxiety was responsible for high inflight anxiety and a constantly high level of motion sickness. | 124 | MSSQ, STAI (before and after), SSQ-TS |
| (Pot-Kolder et al., 2018) | 2018 | A positive correlation was found between anxiety and cybersickness. | 170 | SSQ, SUD |
| (Chen et al., 2016) | 2016 | Anxiety disorder patients may have an increased risk of developing vertigo, especially those who are female or have cerebrovascular disease. | 15,470 | Self-reported rating |
| (Meissner et al., 2009) | 2009 | Higher cortisol levels are associated with higher motion sickness susceptibility. | 32 | MSSQ |

The work described in (Garrido et al., 2022) presented a detailed explanation of how stress contributes to the severity of cybersickness. The study involved 92 participants who were assessed for susceptibility to both physical and cognitive stress. It was found that individuals with greater vulnerability to these stress forms experienced more pronounced cybersickness symptoms. To gauge the extent of cybersickness, the study employed the Virtual Reality Sickness Questionnaire (VRSQ) before and after VR exposure and incorporated the five scales from the Copenhagen Psychosocial Questionnaire version III (COPSOQ III) to measure stress.

The study has an extensive participant database of 15,470 individuals (Chen et al., 2016). The findings highlight a significant correlation between anxiety disorders, a condition closely linked to stress, and the occurrence of vertigo, a symptom commonly associated with both motion sickness and cybersickness. They used self-reported ratings to establish that individuals, particularly women or those with cerebrovascular disease, who are prone to anxiety are predisposed to experiencing vertigo. Next, Meissner et al. (2009) report on the role of cortisol, a hormone that affects several aspects of the body and mainly helps regulate the body's response to stress, causing increases in heart rate and blood pressure. The study indicates a clear connection between higher cortisol levels and an increased susceptibility to motion sickness. With 32 participants, the research employs the Motion Sickness Susceptibility Questionnaire (MSSQ) to quantify this relationship, the findings suggest that stress responses may predispose individuals to motion sickness.

The study described by Pot-Kolder et al. (2018) explored the relationship between anxiety and cybersickness, revealing that stress-induced anxiety may be a strong indicator of one's likelihood to experience cybersickness. This study involved 170 participants and used the Simulator Sickness Questionnaire (SSQ) along with the Subjective Units of Distress (SUD) scale. The findings also confirm that this significant correlation is observed in healthy individuals rather than patients. Given that anxiety levels appear to mediate the symptoms of cybersickness, it is anticipated that reducing anxiety could lead to a corresponding decrease in cybersickness.

Lastly, the study by Stelling et al. (2021) shows the role of trait anxiety, which is a high and constant level of anxiety, with an increased level of motion sickness. This study engaged 124 participants and used the Motion Sickness Susceptibility Questionnaire Short (MSSQ), State-Trait Anxiety Inventory (STAI), and Simulator Sickness Questionnaire-Trait (SSQ-TS), to measure this relationship. The results indicate that continuous stress exposure can significantly impact the onset of cybersickness.

### Link Between Cognitive Load and Cybersickness

Cognitive load in VR training for law enforcement is an essential factor to consider, particularly given its potential impact on cybersickness. Cognitive load refers to the mental demand placed on an individual while engaging with VR simulations that often require multiple simultaneous tasks, such as navigating, communicating, and decision-making under conditions that can induce real stress as a response to the simulated scenarios. The influence of cognitive load on cybersickness has been a subject of interest in recent research, especially in the context of VR experiences. The interaction between cognitive load and cybersickness is nuanced, with studies indicating both increases and reductions in cybersickness symptoms under different cognitive loads. These variations are detailed in Table 2, which summarizes the findings of the relevant studies surveyed herein.

**Table 2.** Studies examining the relationship between cognitive load and cybersickness symptoms.

| Ref | Year | Results | Nb of Participants | Questionnaires |
|---|---|---|---|---|
| (Pöhlmann et al., 2023) | 2023 | Users performing a cognitive task while experiencing a VR rollercoaster reported reduced symptoms of cybersickness. | 40 | SSQ (before and after) NASA-TLX: mental demand |
| (Sepich et al., 2022) | 2022 | Simple task did not significantly increase sickness while a more complex task made individuals sicker. | 151 | SSQ, NASA-TLX |
| (Park, 2020) | 2020 | Mental effort for cognitive load was positively correlated with cybersickness. | 64 | SSQ |
| (Zhou et al., 2019) | 2019 | Administered cognitive distraction can accelerate the rate of habituation to a VR environment, therefore lowering users' levels of cybersickness faster. | 14 | SSQ, PQ |
| (Bos, 2015) | 2015 | Adding mental distractions reduced the levels of sickness experienced. | 16 | MSSQ |

The most recent study from 2023 (Pöhlmann et al., 2023) found that engaging users in a cognitive task while experiencing a VR rollercoaster led to a reduction in cybersickness symptoms. This study involved 40 participants and utilized the SSQ to assess changes in symptoms before and after introducing cognitive tasks gauged by the NASA Task Load Index (NASA-TLX) to measure mental demand. This study also looked at the analysis of brain activity data via a functional near-infrared spectroscopy system, suggesting that active engagement in tasks may serve as a distraction, potentially mitigating the adverse effects of VR.

In contrast, the research described in (Sepich et al., 2022) reported that task complexity plays a role in the experience of cybersickness. Participants involved with a more complex workload task within the same virtual environment reported increased symptoms of cybersickness compared to those engaged in simpler tasks. This study, with 151 participants, combined the SSQ and the NASA-TLX to measure the effects of task complexity on cybersickness. This suggests that while cognitive engagement can be beneficial, there is a threshold beyond which the cognitive load can become overwhelming and accentuate cybersickness.

Similarly, the study by Park (2020) demonstrated that mental effort from cognitive load was positively correlated with cybersickness with nursing students engaged with 360-degree video content. This correlation was found through a study of 64 participants using the SSQ. The study found that mental effort was positively correlated with cybersickness, indicating that increased cognitive demands, such as those required for learning complex skills, could contribute to the discomfort experienced in VR.

In turn, the research by Zhou et al. (2019) presented a different perspective, positing that cognitive distraction might facilitate habituation to virtual environments, thereby reducing cybersickness over time. This hypothesis was evaluated through a human subject study where 14 participants received cognitive distractions during immersion in VR and responded with the SSQ and the Presence Questionnaire (PQ). Although the results showed a trend towards reduced cybersickness, the findings were not statistically significant, suggesting the need for further research with a larger sample size to clarify the impact of cognitive distraction.

Finally, the study by Bos (2015) found that adding mental distractions could reduce the levels of sickness experienced. This research engaged 16 participants and used the MSSQ. The study demonstrated that engaging participants in an audio letter memorizing task while exposed to motion videos reduced sickness levels. This finding also supports the idea that cognitive distraction can be an effective solution to motion-related discomfort in VR.

## Link Between Movements and Cybersickness

In VR training for law enforcement, officers are required to stay alert, constantly looking around and performing numerous head movements as they would in real-world scenarios. This level of physical engagement is critical to replicate the demanding conditions of law enforcement duties. However, if the VR scene fails to seamlessly follow these movements, it can lead to a mismatch between what the user sees and expects to see, potentially inducing cybersickness. It's essential to understand how such movements may affect cybersickness to improve VR training effectiveness and user comfort. The detailed relationships between head movements and cybersickness are elaborated in Table 3, which presents a summary of the surveyed research findings.

The study by Pöhlmann et al. (2022) examined the impact of head movements on cybersickness, finding that perceived motion in VR, even without actual simulated movement, could induce vection and cybersickness. This study explored the effects of the optimized Fraser Wilcox illusion, an anomalous motion illusion, on 31 participants, reporting that while head movements occurred, they were unrelated to the properties of the stimuli, indicating no direct correlation between the amount or direction of head movements and the occurrence of cybersickness. Instead, perceived visual motion was sufficient to elicit vection. The study suggests that dizziness might be the linking factor between cybersickness symptoms, vection, and the lack of a direct relationship between head movements and postural instability experienced in VR.

The study by Palmisano et al. (2017) with 13 participants investigated mismatches between perceived and physical head movements and their contribution to cybersickness. It was found that such mismatches can strongly influence the experience of cybersickness, with negative relationships indicating that stronger vection was associated with less movement. This study emphasizes the technological aspect of VR training, where accurate motion

tracking is crucial to minimize the sensory conflict that can cause cybersickness. Another angle was presented in the study by Sasaki et al. (2016), involving 27 participants, which did not focus on cybersickness directly but found significantly higher salivary secretion, a symptom of cybersickness, in the presence of body movements. This finding points to a physiological response that could correlate with the sensory conflicts inherent in VR experiences.

Lastly, the study by Walker et al. (2010) with 48 participants observed that subjects with the highest sickness scores, assessed via the SSQ questionnaire, moved their heads less often than others in the VR environment. This study suggests that there may not be a straightforward link between the quantity of head movement and the level of cybersickness experienced, as less movement was observed both in those experiencing high levels of sickness and in the VE compared to the real world.

**Table 3.** Studies examining the relationship between body/head movements and cybersickness symptoms.

| Ref | Year | Results | Nb of Participants | Questionnaires |
|---|---|---|---|---|
| (Pöhlmann et al., 2022) | 2022 | Head movements were unrelated to any stimuli properties, suggesting that the motion signal elicited by the illusions might not have been strong enough to cause postural instability. Dizziness has been identified as the possible link with head movements. | 31 | SSQ |
| (Palmisano et al., 2017) | 2017 | A mismatch between perceived and physical head-movements can contribute strongly to cybersickness. Negative relationship – whereby stronger vection was accompanied by reduced cybersickness. | 13 | SSQ |
| (Sasaki et al., 2016) | 2016 | They found significantly higher salivary secretion in the presence of body movements. | 27 | N/A |
| (Walker et al., 2010) | 2010 | Subjects with the highest sickness scores moved their heads less often than other subjects in the VE. | 48 | SSQ |

## DISCUSSION

This survey has revealed nuanced insights into the connection of stress, cognitive load, and physical body/head movements within VR environments

and their impact on cybersickness. Stress emerged as a critical factor where high-intensity training scenarios can induce significant stress levels in users, increasing the symptoms of cybersickness. The findings have highlighted a clear trend: as stress levels increase, so does the level of cybersickness. This correlation emphasizes the necessity of managing stress within VR training to minimize its impact on users, suggesting a sensitive balance between creating realistic training and maintaining user comfort. Supporting this finding is a study on clinical predictors of cybersickness, where among highly stressed individuals, managing stress responses showed to significantly reduce the incidence of cybersickness in VR settings (Kim et al., 2021).

Regarding cognitive load, the data presents a more nuanced view. On one hand, high cognitive load, resulting from the simultaneous management of multiple tasks and decision-making under pressure, was shown to accentuate the cybersickness symptoms by overloading the user's processing capacities. On the other hand, depending on the type of activity leading to higher cognitive load, the activity may serve as a distraction, reducing the perception of sensory conflict and diminishing symptoms of cybersickness. That said, the studies with larger numbers of participants confirmed the positive correlation between cognitive load and cybersickness, indicating that excessive cognitive load can indeed amplify the symptoms of cybersickness. This highlights the need to balance cognitive demands in VR training to mitigate cybersickness while enhancing learning effectiveness. This is corroborated by Frederiksen et al. (2020), which showed that effective management of cognitive load could improve user comfort and training outcomes.

Lastly, movements, particularly head movements, are a natural part of law enforcement officers' activities and are necessary for the realism of VR training. Head movements take on a critical role due to their necessity to scan the environment in various training scenarios. The survey showed, however, a clear negative correlation between head movements and cybersickness. This could indicate that well-synchronized head movements with the VR environment may actually help reduce the sensory mismatch that causes cybersickness. When VR systems successfully capture and mirror the user's head movements, cybersickness symptoms can be significantly reduced. This finding suggests that ensuring precise sensory alignment between the user's physical movements and the VR environment's visual feedback is essential in minimizing cybersickness. When the virtual environment fails to replicate their movements accurately, the resulting sensory lag can lead to an increase in cybersickness (Palmisano et al., 2020).

Understanding the dynamics of how stress, cognitive load, and movement affect cybersickness is crucial for the development of future VR training protocols. It is evident that training programs must navigate the fine line between creating realistic, high-stress scenarios that prepare officers for real-life situations and ensuring that these scenarios do not induce cybersickness. To reduce cybersickness in VR training for law enforcement, our recommendations emphasize the adoption of state-of-the-art VR simulators and headsets with the highest possible display resolution and quality, as well as head motion tracking.

The literature suggests that an adequate pixel density and display resolution can significantly enhance performance and reduce motion sickness and eye strain (Kourtesis et al., 2019). Moreover, a higher refresh rate, ideally ranging between 75 Hz to 120 Hz, is critical as it ensures that images are updated frequently to match the rapid head movements of officers during training, thereby reducing the gap between head movements and display updates (Lawson et al., 2022). A dynamic field of view (FoV) should also be considered, as a wider FoV can actually increase cybersickness, which may lead to more nausea and disorientation (Fernandes and Feiner, 2016). Foveated rendering, which provides high resolution at the user's gaze focus and gradually decreases resolution towards the periphery, has been shown to improve performance and reduce (Lin et al., 2020). Implementing this technology in VR headsets could dramatically improve the training experience for officers. Another factor to consider is the interpupillary distance (IPD), which must be correctly adjusted to match the distance between a person's pupils. This adjustment is crucial to avoid visual discomfort, poor depth perception, eye strain, and distorted images (Seiler et al., 2022). The latest generation of VR headsets, such as the Pimax Crystal and Varjo headsets, incorporate technology that automatically adjusts this parameter to fit the user's unique IPD, further reducing the risk of cybersickness.

Incorporating these hardware advancements, along with psychophysiological measures, into VR training protocols should lead to major improvements in VR training (Muñoz et al., 2020). The integration of systems capable of collecting objective data directly within the VR headset, such as the one described in (Cassani et al., 2020) to monitor biosignals directly from the VR headset, offers a promising avenue for real-time adaptation of simulations. By using such data, training programs can dynamically adjust the intensity of simulations to the individual's response, potentially reducing cybersickness and enhancing the overall efficacy and comfort of the training (Dennison et al., 2016). This approach not only has the potential to improve the immediate user experience but also to refine the long-term effectiveness of VR training protocols for law enforcement, ensuring that officers are optimally prepared for the rigors of their profession.

## CONCLUSION

The present survey has highlighted the nuanced connection between stress, cognitive load, and physical movement, and their impact on cybersickness. The survey has suggested a positive relationship between cybersickness and both cognitive load and stress. In contrast, head movements within virtual environments have been shown to have a negative correlation with cybersickness. Addressing these cybersickness challenges can help unlock the potential of VR for training of law enforcement officers. The findings of this survey could inform technological advancements that can be incorporated into future protocols to positively enhance officers' performance, comfort, and outcomes when using VR for training.

## ACKNOWLEDGMENT

The authors would like to acknowledge funding from the Natural Sciences and Engineering Research Council of Canada and MITACS under the Alliance Grants Program (ALLRP576732–22).

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