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USER ADAPTATION TO CYBERSICKNESS IN VIRTUAL REALITY: A QUALITATIVE STUDY

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Research paper

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Abstract

Virtual reality has been gaining attention due to its capacity to immerse users into virtual environments. However, it has been reported that many users experience physical discomfort caused by cybersickness. Despite the increasing scholarly and practical attention paid to virtual reality, the influence of cybersickness on user experience is unclear, and research findings are inconsistent. Some researchers argue that cybersickness negatively influences user experience by significantly decreasing enjoyment and perceived presence, yet some studies reveal insignificant associations between cybersickness and user experience. The conflict between such results remains unsolved. Therefore, this study seeks to provide more a nuanced understanding of how users experience cybersickness. Toward this end, this research employs a qualitative approach using the interview method and derived factors associated with cybersickness triggers, symptoms and user adaptation. Based on the findings of this research, we propose a time-varying cybersickness model that accounts for the interplay between cybersickness triggers, symptoms, and user adaptation.

Keywords: Cybersickness, User adaptation, User experience, Time-varying cybersickness model.

1 Introduction

Virtual reality (VR) has become increasingly popular in recent years because it immerses users into virtual environments that can simulate real-life experiences. Many VR applications have successfully engaged users in the fields of training, education, marketing, entertainment, and healthcare (Lee *et al.*, 2013; Wojciechowski and Cellary, 2013). However, it has been reported that VR often has negative consequences, such as physical discomfort (including disorientation, nausea, and eye strain), which are commonly known as cybersickness—a type of motion sickness specific to VR (LaViola Jr, 2000).

Cybersickness is an important topic in VR literature. Researchers have found that cybersickness negatively influences user experience by reducing the extent to which people perceive presence (Witmer and Singer, 1998) and enjoyment (Lin *et al.*, 2002a), thereby significantly hindering user engagement. Furthermore, it has been reported that some symptoms (e.g., nausea and vomiting) may linger for hours or even days after the use of VR (Ilyas, 2012). Thus, cybersickness is one of the main factors that causes people to discontinue VR use (Fernandes and Feiner, 2016). The issue of how cybersickness can be eliminated or minimized is critical in VR research.

By contrast, some studies have found that cybersickness does not always significantly hinder user experience (Nichols *et al.*, 2000; Ling *et al.*, 2013; Von Mammen *et al.*, 2016; Tiiro, 2018). According to these studies, some users interpret cybersickness as part of the VR experience, and thus, still appraise their experience as highly enjoyable (Von Mammen *et al.*, 2016). There is evidence for this phenomenon in some studies that found that cybersickness does not lead to a decrease in perceived presence (Ling *et al.*, 2013; Tiiro, 2018) or enjoyment (Nichols *et al.*, 2000; Von Mammen *et al.*, 2016). These inconsistencies and conflicts between results related to the relationship between cybersickness and user experience motivate the current study.

To remedy the gap in the research, this study examines how users interpret and respond to VR-induced cybersickness. By providing a nuanced understanding of cybersickness from the perspective of user adaptation, this study extends the theory of user adaptation, thereby contributing to the VR literature. The research findings also inform VR designers about how to alleviate negative experiences during the initial use of VR.

2 Related Work

2.1 Cybersickness Symptoms

The diverse symptoms of cybersickness are grouped into three dimensions: nausea, disorientation, and oculomotor (Kennedy *et al.*, 1993). The symptoms classified as nausea include sweating, increased salivation, stomach awareness, and occasionally even vomiting (Kennedy *et al.*, 1993). Although actual vomiting or serious nausea has rarely been observed in current VR use, some users experience these symptoms at moderate levels and consequently discontinue their use of VR. Another dimension of cybersickness, disorientation (or dizziness), is manifested as unsteadiness of posture (e.g., standing or walking), which is reported to be short-lived after exposure to virtual environments (Riccio and Stoffregen, 1991). The third dimension of cybersickness is related to oculomotor symptoms (or visual symptoms), such as eyestrain, blurred vision and difficulty in focusing (Kennedy *et al.*, 1993). These visual symptoms have been identified as the predominant VR-induced cybersickness symptoms (Barrett, 2004).

2.2 Cybersickness Triggers

The causes of cybersickness have been identified from three aspects in previous studies: technological, task, and individual factors. Technological factors include time lags between a user's head movement and the recomputation/presentation of VR content the user intended to see (Hettinger and Riccio, 1992).

For example, users experience cybersickness when they quickly change their orientation in seconds while wearing a head mounted display (Broeck *et al.*, 2017), with VR content not following their head movement in real time (Kasahara *et al.*, 2015). The conflict between the visual information and the user's body perceptions causes cybersickness.

Task factors refer to task characteristics in VR content, including task controllability and task duration (Davis *et al.*, 2015). When users perform certain tasks in VR. VR content sometimes provides visual effects that give users an illusion of body motion (i.e., vection) while their bodies are physically stationary. Despite the sense of vection, the user is not actually moving. The coexistence of the sense of vection and stationary reality generates visuo-vestibular cue conflicts, which lead to cybersickness (Bonato *et al.*, 2008). However, if the VR task design could enable high user controllability, users can better predict future motion. If the misalignment between the visual motions displayed through a VR head-mounted display (HMD) and the user's physical motion become is reduced, the user will become less susceptible to cybersickness (Kolasinski, 1995). Task duration is another characteristic that causes cybersickness. It has been found that the longer the task duration, the higher the likelihood of cybersickness occurrence (Rebenitsch and Owen, 2016). Kennedy *et al.* (2000) claim that task duration is one of the most important determinants of VR-induced cybersickness.

Individual factors include gender, age, and personal preference in body posture. Researchers have found that female users are more likely than their male counterparts to be susceptible to cybersickness (LaViola Jr, 2000). It has been also found that younger age groups are more likely to experience cybersickness than elderly groups (LaViola Jr, 2000; Davis *et al.*, 2014). It is noteworthy that users have different postural preferences in the use of VR—either sitting or standing postures. Users taking a seated posture are less likely to experience cybersickness than those taking a standing posture (Merhi *et al.*, 2007) partly because sitting may increase users' sense of stability by reducing the demands on postural control, thus alleviating the sense of disorientation (Riccio and Stoffregen, 1991).

2.3 Consequences of Cybersickness

Generally, researchers agree that cybersickness is a set of unpleasant symptoms and can last from a few minutes to several days (Rebenitsch and Owen, 2016). Health and safety is an important area of concern. A possible side effect of cybersickness could be the psychological issues left with the user after they experience certain symptoms of cybersickness. For example, when VR is used for the treatment of health problem, cybersickness symptoms might disturb the treatment and have undesirable effects on patients.

Cybersickness has undesirable consequences beyond the sickness itself. It is also of concern for its potential effects on user experience in VR. The sense of presence has been identified as the defining characteristic, a design goal or a desirable outcome of VR (Steuer 1992; Wilson 1997). Presence is the extent to which the users feel that they are in a particular place even while physically situated elsewhere (Witmer and Singer, 1998). Previous studies have reported conflicting results regarding the relationship between presence and cybersickness. One stream of studies, following the work of Witmer and Singer (1998), has found a significant negative correlation between cybersickness and presence. They argued that cybersickness may draw attention away from the VR and thus decrease presence (Witmer and Singer, 1998). Another group of studies, including Slater *et al.* (1993), Liu and Uang (2011), and Seay *et al.* (2001a), have found a positive correlation between presence and cybersickness. One explanation for the positive correlations is that certain factors, such as field of view (Lin *et al.*, 2002b) and individual immersive tendencies (Ling *et al.*, 2013), can simultaneously increase presence and cybersickness. Another explanation is that the feeling of presence adds to the incidence of cybersickness (Liu and Uang, 2011). Some studies have found no significant correlation between presence and cybersickness (Liu and Uang, 2016).

Cybersickness is a challenge for the implementation and enjoyment of VR use. Cybersickness determines the overall quality of user experience (Lin *et al.*, 2002a; Calogiuri *et al.*, 2018) because people cease to enjoy their use of VR when they feel unpleasant from nausea or disorientation (Van der Spek *et al.*, 2007). People often discontinue VR use to avoid cybersickness (Fernandes and Feiner, 2016). In this sense, cybersickness is considered a major barrier to sustaining user engagement. However, some researchers have concluded that cybersickness does not significantly influence user enjoyment (Nichols *et al.*, 2000; Tan *et al.*, 2015; Von Mammen *et al.*, 2016), arguing that in a highly interactive VR environment, users' enhanced involvement and excitement override the negative effects of cybersickness on user experience. This relationship between cybersickness and enjoyable user experience is understood only partially, but should be explored in more depth and width.

2.4 User Adaptation

Cybersickness appears to diminish in severity when users become adapted to the VR technology after repeated exposures (Hu *et al.*, 1991; Cobb *et al.*, 1999; Kennedy *et al.*, 2000). Apart from such physiological adaptation, people exhibit the ability to recognize uncomfortable situations in VR and readily adapt on their own initiative. Users may take appropriate or inappropriate actions to avoid cybersickness in VR. Certain factors that have not yet come to light may be in need of consideration.

Previous studies have offered conflicting views about the influence of cybersickness on user experience in VR. Furthermore, user adaptation to cybersickness may distort researchers' understanding of the relationships between cybersickness and user experience, which have not been subjected to systematic analysis. For instance, users may adopt certain types of adaptations to cope with cybersickness induced by certain triggers, and different types of adaptation may have different impacts on user experience. Unravelling the underlying mechanism of the cybersickness would allow for predicting whether the cybersickness would be disruptive, or would be easy to adapt to. To provide a better foundation for future studies of cybersickness and user experience, we explore the relationships between cybersickness and user adaptation empirically.

3 Methods

3.1 Design

To explore how users experience cybersickness while using VR, we conducted a qualitative study. We conducted a series of in-depth interviews with 20 subjects (Mage = 21.7, SDage = 2.55, 50% females) recruited from a university located in Hong Kong. Participants were required to perform two different VR tasks using either a sitting or standing posture. This design enabled our subjects to experience VR in a heterogeneous way, which in turn allowed us to explore cybersickness in relation to many different effects. To control the order effects, participants' exposure to each task was counterbalanced. Semi-structured interviews were conducted after each VR task. The interview data were mixed to gain in-depth perspectives during the analysis phase of the study.

3.2 Stimuli

The nature of the tasks being performed directly influences how users experience cybersickness in VR. To gain an in-depth understanding of cybersickness from the user perspective, we balanced different design factors by carefully choosing two distinct VR motion tasks: the boating task and the sledding task.

These tasks were selected from a list of commercial VR applications. The boating task (Senza Peso, Figure. 1) represented a first-person perspective adventure in a virtual afterlife world. By traveling in a forward-moving boat, participants could observe the fantastic sights along the river. An immersive 3D presentation was adopted. As the application allowed for adaptation based on the participant's height, both sitting and standing postures were recommended by the designers. The participants could explore the virtual environment by turning their head or walking around. To increase the interactive features of the scene, elements like drops of water were designed to pass through the body. However, the interaction was limited, and the participants could not directly interact with the objects during the virtual experience. They could not control the boat's velocity, which remained constant in most situations and occasionally accelerated over a predefined route. There were also several events designed to provide them with a sensation of moving upward or downward.

The sledding task (Totally Realistic Sledding VR, Figure 2) represented a first-person perspective sport on a virtual snowy mountain. By playing like an arcade racer, the participants could jump off cliffs, slide off ramps, and knock trees and stones out of their way. The main objective of the sledding task was to avoid obstacles while trying to achieve the best time possible. A low-fidelity presentation was adopted. The application also allowed for adaptation based on the user's height, and both sitting and standing postures were recommended on the product webpage. The participants could accelerate by passing flags and stop themselves by hitting trees or rocks. By moving their arms to turn right and left, they could change their direction to avoid hitting obstacles. There were also several events designed to provide them with a sensation of moving upward or downward. Table 1 presents a comparison between the two tasks.

We used a 2017 HTC Vive® (High Tech Computer Corp., Taiwan) as the HMD device to offer the fully immersive VR experience. Two handheld motion controllers were provided for interaction with VR stimuli.

3.3 Procedure

The participants were first asked to fill out a consent form to allow the video and audio recording. Personal data including demographic information, personal innovativeness, and prior experience were collected prior to the VR motion tasks. The participants then started to play the first task using either a sitting or standing posture. For the sitting condition, participants sat in a swivel chair. They were instructed at the beginning of the task about the VR content that would be presented and how to handle the interactions by turning the head or moving the arms. All of them were asked to perform the boating task to the end, and to perform the sledding task three times. The duration of each task was around six minutes. For all participants, the order of the two tasks was kept counterbalanced.

After the first task, we started the first interview. The participants then performed another task using the posture alterative they did not use in the first task, after which the second interview was conducted. The entire procedure took about 60 minutes for each participant. The audio of each interview was recorded.

Dimension	VR Boating Task	VR Sledding Task
Genre	Adventure	Sports
Play Position	Seated, Standing	Seated, Standing
Representational fidelity	High	Low
Degree of Freedom	6	6
Interaction	Low	High
Control	Observation by moving head or walking	Locomotion by moving arms and body
Orientation	Up and Down, Forward	Up and Down, Forward
Acceleration	Occasionally	Always

Table 1. Comparison between the two VR motion tasks

Figure 1. VR boating task

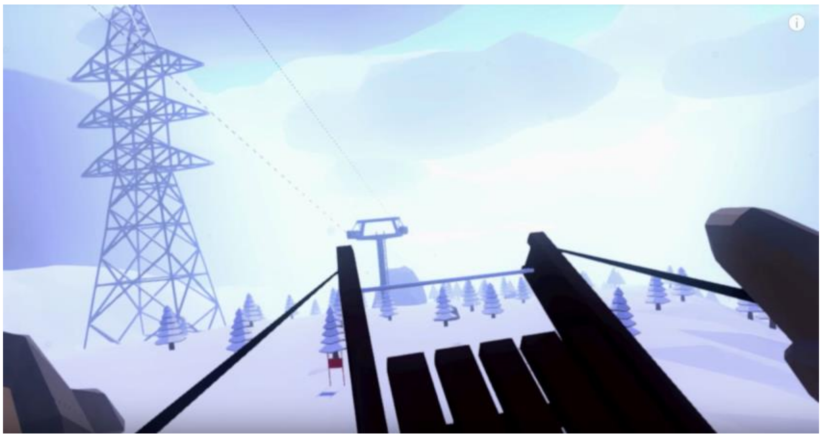

Figure 2. VR sledding task

3.4 Interview Questions

After the completion of both tasks, participants were asked a series of questions, as follows: "How was the overall experience while using the VR?" "Can you describe your thoughts, ideas, or feelings about the use of VR?" "Did you experience cybersickness? Can you describe how it was? When was the most obvious moment of the symptoms?" "To what extent did the cybersickness influence your experience?" Participants' interview responses after each test were collected and analyzed.

4 Results

We analyzed qualitative data collected from in-depth interviews using the thematic analysis method (Braun and Clarke, 2006). We focused on analyzing how participants experience cybersickness and what types of user adaptation were derived from the use of VR. The analysis of the study began with transcriptions of each interview using the audio recordings. Two researchers read the text of the transcriptions independently. Each transcription was scrutinized and coded using a coding scheme developed by one of the authors. The scheme was refined and modified during the coding process. Subsequent sentences were allocated to the newly formed scheme, and new themes were created when the authors felt it was necessary. Inter-rater reliability was checked, and it satisfied the criteria. Once completed, the initial coding results, which included four thematic categories, were reviewed again by one of the authors. The four categories adopted in the qualitative analysis were symptoms, triggers, adaptation, and overall appraisal about the use of VR. Then, 14 specific themes were identified (symptoms of cybersickness, triggers of cybersickness, adaptation, and overall appraisal about the use of VR) (see Table 2).

Category	Identified Factor (*)	Exemplary Quote
Symptoms	eyestrain (oculomotor)	"My eyes are getting wet." / "My eyes are a bit tired now"
	difficulty focusing (oculomotor)	"I can't adjust the focus too much, so, my right eye is not the same as the left eye."
	dizzy (disorientation)	"I feel dizzy." / "I like it, but it made me very dizzy."
	nausea (nausea)	"So I feel a little bit nauseous, but it's okay."
Triggers	vection (task)	"I knew I was standing on the ground, but I still had the feeling of weightless and dizziness during the movement."
	visual demand (task)	"I guess because I had to look more." / "When passing through the shadow of the tower, the contrast is too strong and it seems like a stroboscopic effect."
	task duration (task)	"It became more and more obvious at the end of the game."
	posture (individual)	"It (the feeling of nausea) became more obvious when I stood up."
	head motion (individual)	"It was most obvious when I looked around."
	lag (system)	"Because I turned too fast, the lags occurred. Then I felt dizzy."
Adaptation	physiological adaptation	"Maybe it's my second time to try VR today. I am adapted to it." / "I could not get used to it in the beginning; It became better for the second task."
	cognitive adaptation	"As I felt motion sickness taking a boat in reality, I don't think it disturbs me." / "I understood the technology had limits, and the symptoms were not strong. I could tolerate it."
	behavioral adaptation	"I closed my eyes and had a rest." / "I need to have a rest, because I had the stomachache and felt uncomfortable."
Overall Appraisal about the use of VR	the quality of experience	"I liked it. I think it is very captivating, the images." / "I don't think it (the cybersickness) inhibits my overall experience."

Table 2. Identified themes

(*): dimension identified in the literature

4.1 Symptoms of Cybersickness

We found that individuals experienced cybersickness differently in the same condition. After the boating task, sixteen of the 20 participants reported having had cybersickness to some degree during the boating task; four participants (P2, P3, P14, P17) said they had no cybersickness. Fifteen of the 20 participants reported having had cybersickness to some degree during the sledding task; five participants (P1, P12, P14, P17, P20) said they had no cybersickness.

The coding results showed that several primary symptoms caused by the two VR applications were salient: *eye strain, difficulty with focusing, dizziness*, and *nausea*. The results are consistent with previous studies arguing that VR users report a high incidence of these symptoms. Eye strain was the most frequent symptom reported by participants after each experience. During the interview, the participants tended to highlight the moment when they had the visual symptoms: "My eyes are getting wet" (P11); "When I wanted to focus on something, it happened" (P5); "My eyes are a bit tired now" (P6). Difficulty with focusing was reported to occur at the beginning of the VR tasks: "I couldn't adjust my focus in the beginning" (P2). The participants reported that they felt nauseous and dizzy from time to time, especially when turning their head or having a sense of movement during the tasks.

The results indicate that individuals have different susceptibilities to cybersickness. The occurrence of cybersickness symptoms varied greatly from person to person. Disorientation and oculomotor discomfort were more common than nausea. Because most of our participants reported low or moderate levels of cybersickness, we conjecture that the occurrence of nausea is a premonitory symptom of severe cybersickness. Users who are more susceptible to cybersickness are more likely to have symptoms that are more serious, such as nausea.

4.2 Triggers of Cybersickness

Based on the interviews, we found that six triggers of cybersickness could be detected by participants, which were divided into three task factors (vection, visual demand, and task duration), two individual factors (posture and head motion), and one system factor (lag).

Vection. We found evidence from the interviews to support the relationship between vection and cybersickness. Participants who reported strong feelings of vection often stated that they had symptoms of cybersickness concomitantly. For example, P3 said, "I found the falling and I found going down because of speed … I think I like it, but my body doesn't like it." P3 also stated, "When I was falling, it was not good, and the speed was also, I felt dangerous…" This evidence supports findings in the prior literature that an extreme downward motion can markedly increase cybersickness (Lawson, 2014), especially when a VR scene contains rapid movement (Jerald, 2015). Another participant (P7), who had feelings of both vection and cybersickness, stated, "I felt weightless and dizzy when I jumped down…" and "I knew I was standing on the ground, but I still had the feeling of weightlessness and dizziness during the movement." We also observed that one participant (P12) could not control her posture during the sledding task. During the interview, we confirmed that she had feelings of dizziness when she jumped off a high platform in the game.

Visual Demand. Two participants (P5, P9) reported that cybersickness symptoms occurred when they tried to look more details in the virtual environment. Specifically, our participants mentioned that factors such as flickering (P11) and high contrast (P7) could cause eye strain. The VR content used in the study can have a flickering effect, which is distracting and causes eye fatigue. We found that the flicker fusion frequency threshold varied from person to person. P11 mentioned that the flicker issue was obvious during the boat experience, whereas other participants did not mention this. Individuals with a lower threshold would be more vulnerable to visual and other symptoms. The high contrast of visual stimuli was found to exacerbate the eye burden and was associated with cybersickness. For example, P7 said, "When passing through the shadow of the tower, the contrast was too strong and it seemed like a stroboscopic effect." P5 also mentioned that he paid too much attention to the visual simulation, which made him feel dizzy. Additionally, P4 stated, "I felt better because of less visual efforts [during the sledding task]."

Task Duration. Our participants mentioned that increasing the exposure time could worsen cybersickness. For example, P4 said, "It became more and more obvious at the end of the game" after the boating task. P5 said, "After one or two more games, I was not comfortable." P6 stated that the feeling of dizziness became more obvious during the boating task because it was the second game. However, the effect varied from person to person. P6 said that he did not have severe symptoms because each task lasted no more than ten minutes.

Posture. Based on the participants' responses and their postures choices, we found that standing participants were more likely to use words relevant to bodily feelings or actual body movement. One explanation is that standing participants had more freedom of movement, which created the opportunities for proprioceptive feedback and a greater range of movement. It is worth noting that the standing posture was highly relevant to the feeling of falling and the feeling of dizziness. For example, P9 said, "It [the feeling of dizziness] became more obvious when I stood up." Several participants mentioned feeling like they were going to fall in some scenes. All of these participants adopted a standing position except for P3, who was the most sensitive participant in the study. This perception of falling can be explained by a dysfunction of the vestibular system that makes it difficult for people to control their postures while standing.

Head Motion. Four participants (P4, P6, P9, P12) stated that the most severe instance of experiencing cybersickness symptoms was the moment when they turned their head to look around. For example, P9 said, "I guess it's because I had to look more, had to move my head more." P6 stated, "It was most obvious when I looked around." P12 said, "When I moved slowly or stood still, the dizziness became less."

Lag. The lag issue was the only system factor mentioned by our participants. Our qualitative data supports previous findings that the time lag could be a cause of cue conflict and consequent cybersickness. As P12 mentioned, "Because I turned too fast, the lags occurred. Then I felt dizzy."

4.3 User Adaptation

Three different types of adaptation to cybersickness were identified in this study: behavioral, cognitive, and physiological adaptation. Behavioral adaptation refers to the actions users take to cope with the cybersickness they experience. We identified several actions of behavioral adaptation, including temporary suspension, attention transfer, adjusting/holding the HMD, closing the eyes, and changing posture. For example, previous literature has indicated that some users intentionally slow their head movements significantly to cope with cybersickness symptoms (e.g., dizziness) or temporarily suspend the use of VR after they experience severe nausea or physical discomfort (Ruddle, 2004). Cognitive adaptation occurs when the user believes that cybersickness is either real or a normal part of the VR experience. Thus, they appreciate or tolerate cybersickness through their adaptation. Consistent with previous studies (Lawson, 2014; Jerald, 2015), we also found that physiological adaptation occurred when the user was exposed to VR stimuli continuously and repeatedly. In the next section, we discuss user adaptation and its different types in more detail.

4.3.1 Behavioral Adaptation

A common adaptation mentioned in prior research is *temporary suspension*. In our study, only one participant (P3) had severe cybersickness and stopped the task after two rounds during the sledding task. She mentioned, "I needed to take a rest, because I had a stomachache and felt uncomfortable." Two participants (P7, P17) expressed the intention to stop and take a rest if the cybersickness became stronger.

We found that most of our participants tried to cope with visual symptoms (e.g., eye strain) caused by cybersickness. We observed that P7 made a behavioral change to respond to cybersickness by choosing a different sledding routine and avoiding passing through the tower in the environment. He explained that he tried to avoid the high-contrast visual stimuli that could exacerbate the eye burden. Similarly, P18 said that he looked at the dark area in the virtual environment when he felt that the light was too strong. We labelled such a behavioral adaptation as *attention transfer*. Another behavioral adaptation identified in our study was *adjusting/holding the HMD*. Several participants (P5, P8, P14, P16) had tried to adjust or hold the HMD to overcome the eye discomfort. P16 stated, "If it became blurred, I would adjust a little bit." Four participants (P15, P16, P18, P20) mentioned that they would *close the eyes* for several seconds if they felt eye discomfort. P16 said, "I closed my eyes and had a rest."

Although we required the participants to either sit or stand for the duration of the tasks, we found that some participants noticed that their body position caused their feelings of cybersickness. For example, P8 tried to *change posture* when she felt nauseated while using a standing posture during the sledding task: "I think I felt dizzy when standing up; it was more intense." Some participants mentioned that they had the intention to change their posture because they felt that there were some limitations to the posture they had taken initially. If they had the chance to try again, they would use another posture. For example, P1 mentioned, "I would have liked to sit down because I felt tired wearing the HMD." P7 also stated, "I felt I should sit down. It was not like dizziness, just discomfort. I will feel better with a sitting position if I play the game again." To overcome the symptoms caused by turning their head, participants chose to *change their speed and angle of head or body turning*. P12 mentioned, "Maybe I turned too fast, and I felt dizzy. Then I stood still, turned in a smaller angle, and moved more slowly. It was all right then."

4.3.2 Cognitive Adaptation

To avoid the sense of physical discomfort caused by cybersickness and to go on with given tasks, participants created their own meanings of cybersickness while using VR, which we call *positive appraisal*.

Participants reconceptualized a new meaning of cybersickness by reflecting on past real-world experiences that involved a similar experience of motions (e.g., the boating/sledding task). As P7 mentioned, “I have the same feelings when sledding in reality. I think it is one of the parts you have to experience to play this sport.” This cognitive adaptation renders the cybersickness less disruptive. Similarly, another participant (P4) believed these symptoms during the boating task made the whole experience become real. She stated, “As I felt motion sickness taking a boat in reality, I don’t think it disturbs me.”

Another group of participants conceptualized cybersickness as a normal experience and *tolerated* its existence. For example, P13 stated, “I understood the technology had limits, and the symptoms were not strong. I could tolerate it.” P19 had symptoms of eye strain and believed it was normal because he had a similar experience when using a smartphone. P20 said, “I could understand why it happened.” “I tolerated it, because it was not that much.”

4.3.3 Physiological Adaptation

Some participants reported that they felt that cybersickness diminished when they used the same application repeatedly. After the sledding task, P5 mentioned, “I was not used to it for the first and second round” and, after the boating task, “I could not get used to it in the beginning; it became better for the second task.” The task duration increased the severity of his cybersickness after the first round; however, repeated exposure made him feel better in the end. P1 clearly stated, “Maybe it’s my second time to try VR today. I am adapted to it.” P12 said that her stability and cybersickness improved significantly after repeated exposure to the same visual stimuli. Among the participants reporting the bodily adaptation, two (P1, P12) had used the VR several times before the interview, which suggests that bodily adaptation is valid for users with prior experience.

4.3.4 Triggers and Adaptation

It is important to identify the immediate triggers of cybersickness that can be detected by users. On this basis, we can understand the links between the triggers and the subsequent adaptation, especially the behavioral adaptation. Based on our results, we determined that participants made different types of adaptation to alleviate the cybersickness triggered by different factors, which are listed in Table 3.

Apart from the triggers, we found that the differences between the two tasks had an impact on the triggers and user adaptation. Users reported more cybersickness induced by vection after the sledding task, and more cybersickness induced by visual demand after the boating task. Users preferred ‘approach’ adaptation (e.g., positive appraisal, attention transfer, posture change) during the sledding task, and ‘avoidance’ adaptation (e.g. closing eyes, tolerance, temporary suspension) during the boating task.

Triggers	Adaptation
Vection	temporary suspension, positive appraisal, tolerance, repeated exposure
Visual demand	attention transfer, HMD adjustment, closing eyes, tolerance
Task duration	temporary suspension
Posture	attention transfer, posture change (intention)
Head motion/Lag	changing the speed and angle of head or body motion

Table 3. Triggers and adaptation

4.4 Overall Appraisal about the Use of VR

Although participants were generally positive about their VR experience, we found that some of the participants experienced significant levels of cybersickness. It was noteworthy that even well-designed and popular VR applications caused cybersickness to some extent. P3 and P8 were the participants who reported the most severe cybersickness. For these participants, cybersickness significantly decreased their enjoyment of VR. P8 mentioned, “Cybersickness makes me not want to play the games again.”

However, our study revealed that cybersickness did not always have a serious negative influence on the overall user experience. Participants with moderate levels of cybersickness reported that it was not a significant detriment to their overall VR experience. We found that if participants were sufficiently immersed and felt high levels of enjoyment, their positive experiences overrode the negative effects of cybersickness in terms of their overall enjoyment. We also found that participants coped with cybersickness through adaptation. Cybersickness was interpreted as one component of realness for some participants. P18 mentioned that a moderate level of cybersickness contributed to a good experience, because such feelings made the VR scenario seem more real. Some participants believed that cybersickness was similar to what people would experience doing the corresponding real-world activities. Such cognitive adaptation made cybersickness less disruptive, which helped participants cope with cybersickness while maintaining high levels of presence in the VR environment.

4.5 Time-varying Cybersickness Model

To better understand the relationships between cybersickness, user adaptation, and the quality of experience, we propose a time-varying cybersickness model with trigger factors and adaptation factors based on the work of Kiryu and So (2007) (see Figure 3). First, research has shown that duration and repeated exposure are significantly related to sickness outcomes. In the initial period, physiological adaptation plays a role in reducing cybersickness, so there is a decrease of cybersickness in the adaptation period. As time goes on, the feeling of cybersickness accumulates. Second, we posit that such adaptation could play an important role in shaping the perception of cybersickness. When there is a significant cybersickness trigger, users can detect it and adapt themselves to it accordingly. Third, users feel unpleasant when the intensity of cybersickness exceeds a certain threshold. The use of adaptation may possibly postpone the emergence of unpleasant feelings.

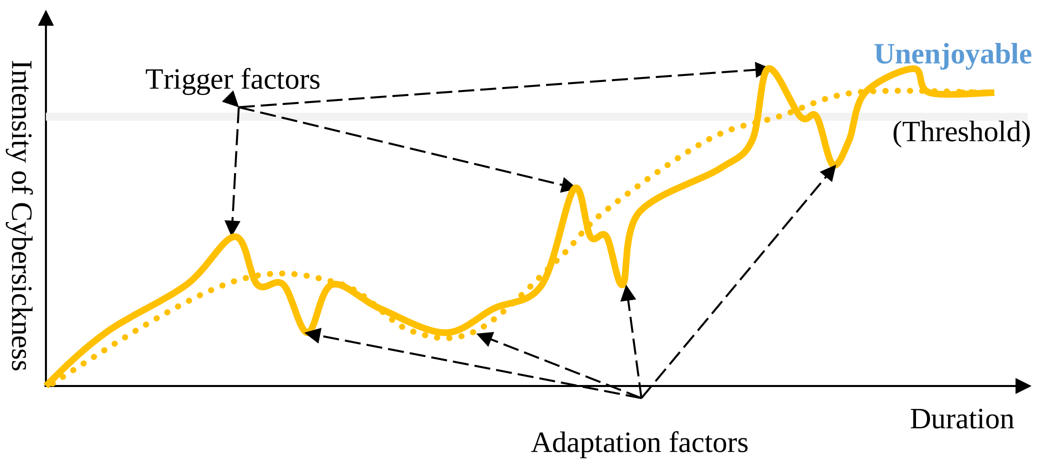

Figure 3. Time-varying cybersickness model with trigger factors and adaptation factors

5 Discussion

The results of this study suggest that users employee different types of adaptation to cope with cybersickness. We speculate that user adaptation alleviates or postpones the negative effects of cybersickness on user experience. In this section, we discuss the study's implications and possible directions for future research.

5.1 Implications for Research

Through our qualitative investigation of cybersickness in VR, we find that (1) cybersickness is triggered by diverse factors including technology, task, and user characteristics, and (2) users cope with cybersickness through adaptation. Different types of adaptation (i.e., behavioral, cognitive, and physiological adaptation) shape the effects of cybersickness on the quality of experience. Our conceptualization of different types of user adaptation in the use of VR provides researchers with a model for understanding the underlying mechanisms for which users cope with cybersickness, thus enhancing the quality of VR experience.

Although cybersickness has been one of the major topics addressed in the VR literature, researchers have mainly focused on technological advancement; relatively little attention has been paid to user adaptation. Our study suggests that users cope with cybersickness through diverse adaptation strategies. The results of this study reveal that users adapt their perception, cognition, and behavior to deal with cybersickness in VR, and that the adaptation shapes the way they perceive the VR experience. For example, in some situations, the experience of disorientation symptoms can be interpreted as a successful simulation of reality. Our findings advance the current knowledge about cybersickness. By demonstrating the existence of user adaptation, this study complements previous studies that have limited their scopes to technological features for reducing cybersickness.

To summarize, by identifying the interplays among trigger factors that can be detected by users, user adaptation, and the quality of experience, we propose a time-varying cybersickness model. The model offers a basis for the comprehensive understanding of the user experience related of cybersickness in the current VR context.

5.2 Implications for Practice

There is general agreement among researchers and designers that cybersickness is a distinctly unpleasant experience, the occurrence of which should be minimized to the greatest degree possible. The present study provides practical implications for designers who seek new ways to promote positive user experience by reducing the occurrence of cybersickness or alleviating its negative influences. The findings of this study can improve designers' awareness of the effects of user adaptation in the use of VR. Our findings also indicate that various VR designs trigger different cybersickness symptoms and user adaptation. Hardware and content developers should not neglect user adaptation when considering ways in which design itself can help users.

In order to harness the benefits of VR technology to enhance the user experience, it is important to understand how to reduce cybersickness without sacrificing enjoyment. Based on our findings, the link between triggers and adaptation is the key to enhancing user experience. It has been found that an effective design for virtual motion creates an opportunity to enhance the user experience (Freeman *et al.*, 2000). However, it is often difficult for users to completely avoid cybersickness in virtual motion scenes. Our findings suggest that users employ certain types of adaptation to alleviate cybersickness induced by virtual motion. VR designers should understand how their target audience interprets the occurrence of cybersickness. In some situations, they can inoculate users so that the experience of cybersickness is interpreted as reasonable or part of a realistic simulation. They can also inform users that feelings of discomfort may be reduced after several exposures. Such techniques should be used strategically to reduce the sense of cybersickness without compromising users' health and safety.

5.3 Future Directions

This study has several limitations that need to be acknowledged. Although our study provides relevant empirical results regarding cybersickness, researchers would benefit from considering method triangulation, for example by employing the quantitative methods and objective measures. Second, the data was collected from undergraduate and master's students of a single university, which may have led to potential biases. The role of user adaptation in alleviating cybersickness should be tested in other populations in the future.

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