Lowering the Effects of Virtual Reality Cybersickness: A Systematic Review

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***Abstract*—Virtual Reality (VR) has several uses in business, entertainment, and training. A simulation sickness known as 'cybersickness' is experienced when using VR. Cybersickness (CS) poses a severe obstacle to VR systems' usability. To fully utilize VR as a medium, it is essential to reduce the uncomfortable sensation of CS. Technology, software, and user attributes all play a role in creating a pleasant VR experience. There is no comprehensive information on what causes cybersickness, how the severity of cybersickness can be assessed, and what factors contribute to CS in a VR environment. Because of this gap, this research aims to unpack the causes of cybersickness, how to assess it, and to identify and describe the factors. A systematic literature review identified 21 factors contributing to VR CS. In addition, a conceptual model was developed to allow researchers and VR developers to evaluate these factors.**

Keywords-virtual reality; simulation sickness; cybersickness; factors; head-mounted display; systematic review.

I. INTRODUCTION

VR has recently become part of everyday vocabulary, which can be partly ascribed to the recent media coverage it has received [1]. Simply put, VR offers a Virtual Environment (VE) that enables users to engage with a highly realistic artificial world made mostly of three-dimensional computer-generated images, audio, and haptic input. VR has been used in various fields, such as healthcare, construction, and architecture. Still, video games have drawn consumers' attention more than other VR applications [2]. The leading technology for virtual worlds is visual devices known as Head Mounted Displays (HMDs), which are very different from standard screens since they completely immerse the user in the VE by obstructing outside visual inputs that can interfere with the experience. A negative side effect known as Cybersickness (CS) has also been identified with such immersive experiences [2].

An unpleasant collection of symptoms called 'cybersickness' is brought on by being in a VE and can linger for a short while or even for days [3]. Examples of such symptoms include headache, nausea, and even vomiting [4]. According to estimates, CS affects 20% to 80% of the population in some way [3]. CS claims have been rising along with the popularity of VR gadgets, despite the fact that the ailment has long been understood and researched [2].

In the worst situations, the symptoms are so severe that people cannot utilize VR equipment. In one instance, game makers were forced to remove VR components from their creations because users complained of feeling unwell [2]. The symptoms of CS may interfere with medical therapy and have unfavourable repercussions on the patient. Even minor symptoms might be unpleasant and bother the user.

A. Problem Statement

VR gives people a chance to imagine a modified three-dimensional world. However, for optimal efficiency, it necessitates total sensory awareness. Interactions and visual signals in the VE must be effectively developed to be as realistic as possible before VR is adequately adapted and understood [4]. Its effectiveness can be measured by how much the user feels immersed in the surroundings [5]. Usability problems, such as the symptoms related to CS, will reduce the feeling of presence in a VE. If users have trouble using the environment, they won't be able to experience the reality of a VE.

Numerous factors lead to CS, and the knowledge base needs a comprehensive view of all that can lead to it. Because of this research gap, this study aims first to identify the factors contributing to CS during VR technology use. Secondly, a conceptual model will be created incorporating these identified factors.

B. Research Objectives

The following are the objectives of this study:

1) *To determine the causes of Cybersickness in the Virtual Reality environment.*
2) *To determine the severity of cybersickness experienced, or susceptibility to it, before, during, or following a Virtual Reality session?*
3) *To determine the factors that contribute to Virtual Reality Cybersickness*

C. Research Questions

This research will address the following research questions:

1) *What are the causes of cybersickness in the Virtual Reality environment?*
2) *How can the severity of cybersickness experienced, or susceptibility to it be assessed before, during, or following a VR session?*
3) *Which factors contribute to Cybersickness during the application of Virtual Reality technologies?*

D. Significance of the Study

This study aims to present a holistic view of all the factors that are posited to cause CS in a VR environment. It seeks to provide current and forthcoming VR developers with helpful guidance on reducing CS symptoms to facilitate a good VR experience. It will also act as a source of information for researchers delving into CS in VR. This will serve as a roadmap for expanding the study and making the link to the variables employed. Additionally, it is believed that this research can aid users who experience CS in VR settings by enhancing their user experience.

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The rest of this paper is organized as follows. Section II provides literature on cybersickness causes and theories, and the measurement methods deployed. Section III presents the research methodology to conduct the Systematic Literature Review (SLR). The results of the SLR are presented in Section IV and a discussion of the research findings are provided in Section V. Section VI concludes the paper and provides recommendations for future research.

II. LITERATURE REVIEW

A. Cybersickness Causes and Theories

1) Sensory Conflict Theory

CS is a disorder that is difficult to categorize since there are a variety of symptoms, the illness's effects differ from person to person, and there are many theories as to how it began [3][33]. The hypothesis discussed the most in literature is the Sensory Conflict Theory (SCT). It contends that CS results from a conflict between the information provided by several senses. It has been demonstrated that common motion sickness signs and physiological modifications, such as car or seasickness, are relatively similar to CS [34]. Additionally, sensory conflict seems to have an impact on both. But the sensory conflict in a car and VR are very different.

When travelling by car, one might perceive acceleration, but their visual surroundings, the vehicle's interior, remain still. This causes motion sickness. According to the SCT, you can lessen the conflict by gazing out the window, bringing the vestibular and visual information back into alignment. In VR, the conflict is going in the opposite direction. While the vestibular sense either detects no motion or is out of sync with the visuals, VR users perceive motion and accelerations through visual cues. This affects how CS is treated differently from traditional motion sickness.

2) Vection

Vection, which refers to the perception of motion through visual stimuli, has frequently been linked to Visually Induced Motion Sickness (VIMS) or CS [35][36]. However, according to other research, vection can happen even when no sickness is present [35]. This shows there is more to the relationship between vection and CS than just a straightforward causal one. In their study, [36], who intended to further explore this connection, discovered that sickness is caused by a shift in vection [36]. From the standpoint of sensory conflict, it does make sense that CS is more often caused by apparent visual acceleration than by continuous visual motion. Conflict happens when one reason detects acceleration while the other does not since the vestibular system can only detect accelerations.

However, the findings of [37] are at odds with those of the study by [36] VIMS was not significantly impacted by the vection's strength or fluctuation. It is posited that [37] may have yet to be able to successfully create a high level of motion sickness, which might account for these conflicting results. Therefore, any potential difference in the ability to generate motion sickness between constant and variable vection may have yet to be able to achieve statistical significance. Humans acquire information about body motion through their vestibular system, which detects the rotational and translational accelerations of the head, in addition to visual data. Therefore, combined with the visual system, the vestibular system is a crucial tool for humans to notice when our body is moving and distinguish between object motion and self-motion [38][39]. When you start moving in VR with a joystick, something other than this multisensory integration may work better. There is a sensory conflict since you can feel vection. Still, the vestibular system doesn't send any signals of self-motion.

3) Postural Instability

Postural instability, a notion that [41] first proposed, is another theory that is frequently brought up. They suggested that symptoms happen when you have not learned how to maintain yourself in that particular situation and are experiencing postural instability. When riding a roller coaster in VR while standing, you might be familiar with this sensation of instability. Various studies appear to contradict one another, with some offering evidence for the theory [42][43], while others either only discovered postural instability as a result of CS or found no causal relationship at all [44]. It still needs to be determined what the exact relationship with CS is. However, this idea offers a foundation for measuring CS objectively.

4) Rest-Frame Hypothesis

The Rest-Frame Hypothesis is another theory that has influenced a typical CS mitigation technique [45]. According to this theory, CS results from the inability to identify or select a stable reference frame, also known as the rest-frame, from which to interpret relative movements, locations, and orientations. The nervous system chooses the rest-frame from among the various reference frames and gives it spatial-perceptual data [45]. According to the theory, the cognitive conflict that results from being unable to identify a single rest-frame compatible with a person's inertial and visual motion signals, rather than the sensory conflict, causes CS [40]. In other words, illness is more likely to be affected by how the user interprets what is moving and what is not based on the degree of competing cues.

B. Cybersickness Measurement Methods

As covered in the section above, there are only a few well-established theories on CS. Similar to this, subjective and objective approaches to assessing CS exist, categorized into physiological state, postural sway, and questionnaires.

1) Questionnaires

The Simulator Sickness Questionnaire (SSQ) is used in most articles. Even though this questionnaire was first developed for military simulators (like flight simulators), it is still the most well-known for CS in VR research. From none to severe, participants assess the severity of 16 symptoms on a 4-point scale. The results are divided into four scores: overall score, nausea, oculomotor, and disorientation. Several researchers have suggested alternatives because the SSQ's primary intent was not VR and was evaluated on highly skilled professionals [46][47]. Both the Cyber Sickness Questionnaire (CSQ) and the Virtual Reality Sickness Questionnaire (VRSQ) published by [46] and [48] can be seen as subgroups of the SSQ. Only nine symptoms remain when the nausea-related symptoms are excluded from the VRSQ.

The Fast Motion Sickness Measure (FMS) is a one-dimensional scale that ranges from zero to 20. This scale which indicates no motion sickness (zero) to severe motion sickness (20), was developed by [49]. It is feasible to gauge the time of the motion sickness since participants vocally rate each minute. The FMS and the SSQ score and its sub scores also show a substantial correlation in other research [49][50]. The Misery Scale (MISC) was developed by

Wertheim et al. as an alternative to the FMS. The scale extends from zero (no symptoms), to ten (vomiting). In addition to verbal responses, a physical dial may also be used to record answers on a one-dimensional illness scale, as [51] study showed.

It might be essential to know a participant's vulnerability to motion sickness in addition to measuring CS during or after a VR session. Participants' susceptibilities to CS can vary. Thus [52] updated Motion Sickness Susceptibility Questionnaire (MSSQ) was developed to gauge this. The participant's history of motion sickness is examined using the MSSQ. The Visually Induced Motion Sickness Susceptibility Questionnaire (VIMSSQ), which looks at prior encounters with symptoms rather than motion sickness in general, was created by [49] since this questionnaire was not designed for CS (or VIMS). [53] also suggested and examined a condensed version of the VIMSSQ in another research study due to its length.

2) Physiological State

Although questionnaires are the most popular way to detect CS, they have certain drawbacks. First, surveys interfere with the user's experience, making it impossible to track their illness in real-time [54]. The fact that surveys are inherently subjective is another disadvantage. As a result, they only sometimes accurately gauge what they are attempting to perform. Researchers can assess the physiological status of the consumers to get past these issues. This is doable in real time and may offer a source of unbiased data.

The user's present status might be assessed by sensors, which would subsequently apply the appropriate CS mitigation techniques. A method that can evaluate CS in real-time using physiological data was developed by many researchers using machine learning [44][55]. Based on physiological data, such as heart rate, breath rate, heart rate variability, and galvanic skin reaction, [55] created an entirely closed-loop system. Based on the determined amount of sickness, it applied Field of View (FOV) reduction or Gaussian blurring, which might lower the level of nausea. The degree of CS was determined by periodically evaluating the user's physiological data. The system's capacity to lessen CS was not put to the test.

Despite being objective, physiological evidence has not been able to displace the SSQ as the gold standard for assessing CS. Physiological outcomes have often been employed in research to support their conclusions rather than as the primary measurement technique. Additionally, the SSQ or other questionnaires frequently validate physiological measures. Therefore, their validity is dependent on arbitrary information.

3) Posturial Sway

Postural sway, which is a type of body movement, has yet to be included in several investigations as an impartial evaluation technique, even if the relationship between postural instability and CS still needs to be fully understood [56]. [57] showed that gait metrics may also be measured to determine CS. They recorded the necessary data using an inertial measurement unit on each foot. They then used a support vector machine which is a machine learning model to create a classifier for CS.

Using a balancing board to measure movements around the center of gravity is one method of documenting postural instability [42][58][60]. After analyzing their data, [58] identified the precise postural sway characteristics that might predict VIMS. According to the findings, those who reported feeling worse had postures that were more circular in form (as opposed to elliptical) and had a higher frequency of forward/backward oscillations. According to each participant's postural sway, [60] trained a deep, short-term memory model that may forecast their likelihood of experiencing CS.

However, there are also sensors in users' Head Mounted Displays (HMD) that may capture postural sway. Head dispersion, or the change in roll and pitch, was put to the test by [59] and shown to be significantly connected to changes on the x- and y-axis around the center of gravity. Participants had to hold their heads motionless or stare straight ahead to assess head dispersion. The relationship between the location information from the HMD and CS was also examined by [61]. They found strong correlations between a few location factors and the SSQ scores, even though the data was pretty noisy. These findings imply that it may be feasible to design a system that collects the HMD's location data, calculates the user's level of CS in real-time, and utilizes that information to modify the methods for reducing sickness.

III. METHODOLOGY

A. Introduction

This research is conducted using a SLR, defined as "*a means of identifying, evaluating and interpreting all available research to a particular research question, or topic area, or phenomenon of interest*" [6]. Simply put, an SLR is a review of primary studies. This study follows the SLR guidelines by [6], which are: identifying sources, study selection, data extraction, data synthesis and writing up the study as a report.

B. Search Terms used in selected databases

"Virtual Reality" AND ("cybersickness" OR "motion sickness" OR "simulator sickness") AND ("factors" OR "fail" OR "break down" OR "flounder" OR "blunder" OR "flop" OR "deteriorate" OR "challenge" OR "issue" OR "problem" OR "obstacle*" OR "success" OR "accomplish" OR "achieve" OR "advance" OR "progress*" OR "realisation" OR "triumph" OR "victory" OR "fruition" OR "attainment" OR "model" OR "method" OR "framework").

1) Source Selection

The following data sources were selected to perform the search:

- IEEE Xplore Digital Library
- Scopus
- ACM Digital Library
- Google Scholar

All of these databases are well-known research repositories in the field of information technology. In addition, Google Scholar was employed to help locate sources via backward and forward citation searches.

2) Selection Criteria

The selection of research material for inclusion in this systematic review was based on this section's inclusion and exclusion criteria.

For a source to be included in the research, it had to meet the following criteria:

- Papers describing the factors that, in a VR setting, lead to cybersickness.
- Papers containing at least three keywords in the title, abstract, or keywords were chosen.

- Journal articles, conference papers, book chapters, dissertations and theses were considered.
- No limitations on publication date.

A source is excluded from the research for the following reasons:

- Papers that don't discuss the factors that contribute to cybersickness in a virtual reality setting.
- Non-English language academic papers.
- If the full text of the publication is not available.
- Duplicate papers meaning the same paper retrieved from different databases.

3) Prisma Flowchart

The search string above was performed on the selected databases, returning 1231 articles. The Google Scholar citation search found an additional ten records. After that, 219 duplicate papers were removed. Screening by the title and abstract was conducted, leaving 213 full-text articles. These full-text articles were further assessed for eligibility resulting in 28 remaining articles used for data extraction and synthesis (see Figure 1). The search was completed in August 2022.

4) Quality Assessment

The included papers were assessed using four quality assessment questions. The questions aimed to evaluate the quality aspects mentioned by [6]. These aspects are characterized as **objectivity** - if the research is free of bias; **reliability** - the accuracy and reliability of the research instruments used; **internal validity** - whether the research was well structured, so data was collected from suitable sources, and **external validity** - determines if the findings can be predicted for subsequent occasions.

Therefore, the following questions were devised to assess the quality of the selected literature:

Q1. Is Virtual Reality and Cybersickness factors the center of the discussion?

Q2. Does the research have a clear goal in mind?

Q3. Does the article clearly follow a research process and describe the data analysis techniques used?

Q4. Does the article report its findings based on evidence and argument?

These questions had three possible answers: Yes and No. Each response is given the following weighting: Yes = 1 and No = 0. The final score was noted and utilized as a scale from 0 to 4 to represent the overall quality of the chosen literature. The articles' outcomes and quality rating are displayed in the results section.

C. Data Extraction

The data extraction was carried out on 28 papers included in the SLR. Thereafter, a qualitative thematic analysis was conducted to synthesize the extracted data. Some of the article's content was highlighted in the paper while it was being read. These ideas/concepts, usually referred to as codes, were carefully investigated to group them into common themes. All the pertinent information that helped in answering the research question was extracted, including the citation, the journal article or conference title, the source database, year published and study type, article sub-concepts, and the main concept. Google Sheets were used to extract data for the thematic analysis.

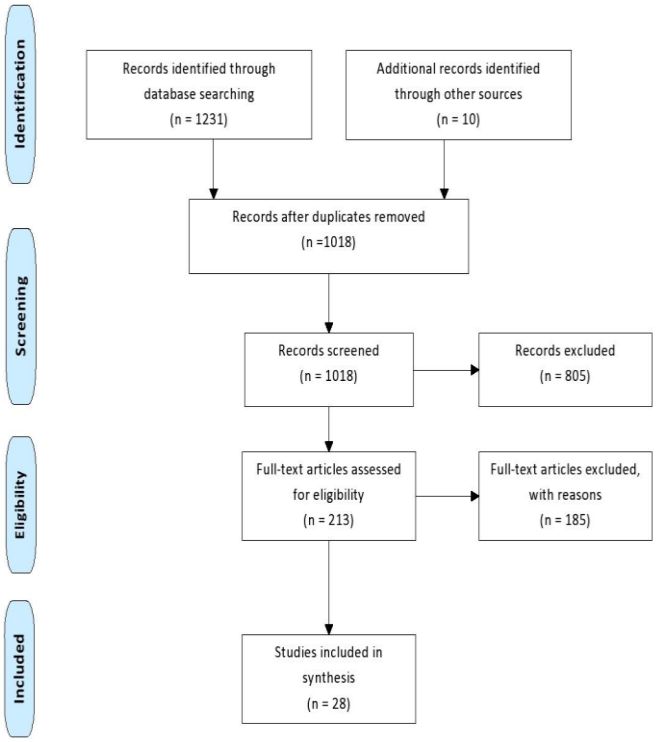

Figure 1. Prisma Flowchart.

IV. RESULTS

A. Search Results

The articles listed in the source selection section were looked at in four databases, which includes Google Scholar. Figure 2 displays the percentage distribution. Most of the articles came from IEEE Explore (41.8%). Scopus accounted for 40.3% and ACM digital library 12.9%. Ten articles (5%) derived from the Google Scholar citation searches.

Most papers included many factors, while some focused on one specific factor. Table I lists these 21 factors and their sources.

B. Quality Evaluation of Articles

Four questions were used to assess the quality of the selected literature, as mentioned earlier. Most papers were of good quality, with an average score of 3.75 out of 4. No paper scored below 3.

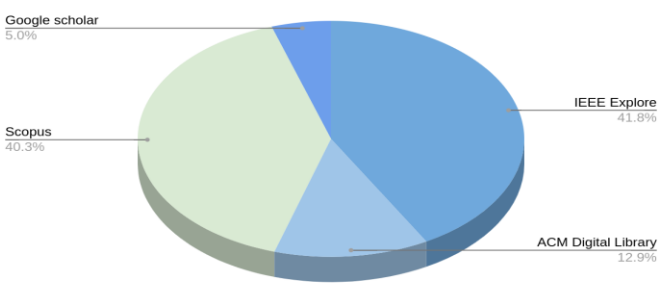

Figure 2. Database articles percentage distribution.

TABLE I. VIRTUAL REALITY CYBERSICKNESS FACTORS WITH SOURCES

Factor	Sources
Habituation	[7][8][9][10]
Duration	[4][7][8][9][11][12][13]
Environmental conditions	[14]
Physical Health	[4][8][15][16][17]
Posture	[4][13][18]
Gender	[4][7][9][12][14][15][19][20][21]
Age	[4][7][12][15][21][22]
Field of View	[7][8][11][12][23]
Flicker	[4][12][21][24]
Screen size	[7][24]
Head mounted displays	[1][5][9][12][14][24][25][26][27]
Lag and Frame Rate	[11][28]
Method of movement	[24][29]
Calibration	[4]
Position Tracking error	[21]
Head motion	[13]
Playing position	[7]
Locomotion	[7][11][12][30]
Immersion	[7][12][31]
Sensory support	[31]
Graphic Realism	[12]

C. *Synthesis of Identified Factors*

A thematic analysis was conducted to identify the core themes and subthemes within the selected literature. The factors were categorized under subthemes and grouped under a theme. Initially, 42 factors were identified as contributing to CS in a VR environment. Upon examination of the definitions of each of these factors and the references made to them by the authors of the selected literature, 21 factors were merged into others resulting in 21 final factors. The remaining 21 factors were further analysed to identify any additional relationships to help categorize them. Categorizing the factors helps to understand the more significant themes and gives deeper insight. The synthesis using a thematic analysis went through 5 iterations resulting in three themes, eight subthemes, and 21 factors. These three common themes were identified as User, Hardware, and Software. Table II lists the synthesized themes, subthemes and the contributing CS factors. A conceptual model depicting these concepts are shown in Figure 3.

TABLE II. SYNTHESIZED THEMES, SUBTHEMES AND FACTORS

Themes	Subthemes	Factors
User	Experience	Habituation Duration Environmental Conditions
	Physical attributes	Physical Health Posture
	Demographics	Gender Age
Hardware	Device	Field of View Screen Size Flicker Head Mounted Displays Lag and Frame Rate
	Tracking	Method of Movement Calibration Position Tracking Error Head Motion
Software	Stabilizing information	Playing Position
	Environment	Locomotion
	Design	Immersion Sensory Support Graphic Realism

V. DISCUSSION

This section of the research aims to answer the three research questions. The core SLR themes identified are 1) User, 2) Hardware, and 3) Software. Each of these themes has sub-themes that translate into factors. The factors under each theme and subtheme are discussed next followed by the addressing the research questions.

A. *Factors Contributing to CS*

1) User: There are differences in CS susceptibility at the user level. These factors include Age, Gender, Habituation, Duration, Environmental Conditions, Physical Health and Posture. Each of these factors are discussed below. These factors are grouped in the subthemes of Demographics, Experience and Physical Attributes.

a) *Demographics:* The Demographics subtheme consists of factors Age and Gender.

Age. According to the literature, younger persons are more resistant to simulation sickness [12]. After the age of 40, people's vestibular perception threshold, or the lowest signal recognized, decreases, rendering them more susceptible to simulation sickness [15]. [22], discovered changes in the postural balance between young and middle-aged test participants. Furthermore, postural balance deteriorates when people become older, which can contribute to illness.

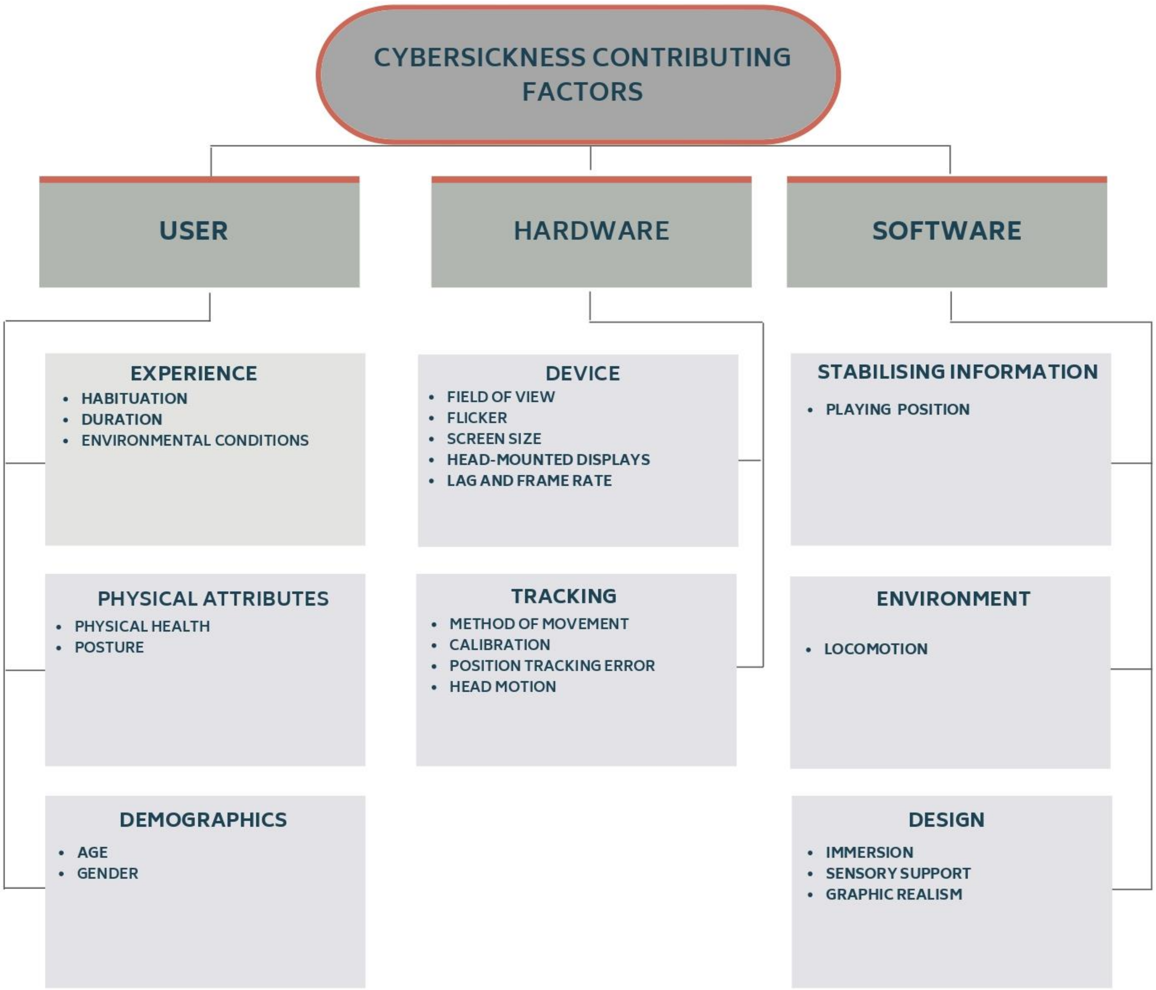

Figure 3. Virtual Reality Cybersickness Conceptual Model.

Gender. Females have consistently been found to be more susceptible than males to CS. With the usage of HMDs, CS may differ depending on gender. [20] investigated the influence of gender and technology and their possible contributions to simulation sickness. Using data from 223 people (108 men and 115 women), they investigated the degrees of simulation sickness concerning gender, sensory conflict, and advancements in VR technology. They concluded that women had a greater level of simulation sickness than males. [14] conducted many trials. They discovered that females were equally susceptible to motion sickness caused by an improper fit of the VR headgear to the inter-pupillary distance (the distance between the centre of one's eyes). They also propose that VR headsets be redesigned with adjustable interpupillary distance to decrease CS in women.

b) *Experience:* The Experience subtheme consists of factors Habituation, Environmental Conditions and Duration.

Habituation. According to [9], an increase in exposure time was directly related to the degree of unpleasant symptoms. Compared to non-susceptible individuals, those prone to motion sickness might suffer nearly double the severity. Users who feel nausea when riding carnival rides might expect to endure unpleasant sensations. Exposing a person to virtual surroundings briefly, halting the encounter before or during illness, and retrying in a day or two will assist the user in acclimatizing to the virtual world. Exposure to virtual settings regularly may reduce or eliminate simulation sickness.

Environmental conditions. CS symptoms worsen in environments with high temperatures and inadequate ventilation. Good airflow and ventilation can help reduce nausea and aid recovery after dizziness [14].

Duration. Several studies have found that more than 10 minutes of VR exposure can cause nausea, and the longer the exposure period, the more severe the VR sickness [7][8][11][12]. According to these studies, the application should allow users to pause the experience for a rest and then resume it later. In contrast, an application might advise users to take breaks regularly to avoid unpleasant sensations [11].

c) *Physical Attributes:* The Physical Attributes subtheme consists of factors Physical Health and Posture.

Physical Health. The user's senses must be at their peak to attain a heightened presence level. For the optimum VR experience, users should be physically fit and have a strong sense of balance. If a user has a hangover, cold, headache, is tired, or is sleep deprived, it is best to avoid a virtual environment since their symptoms may aggravate [11].

Posture. Postural instability is a well-documented consequence of exposure to a Virtual Environment (VE). Postural stability is frequently assessed before and after VE exposure to detect changes in stability caused by the exposure. Less posturally stable individuals are more likely to get CS or suffer from more severe illness when compared to more posturally stable individuals [4][13][18].

2) Hardware

Some factors associated with hardware used in a VE can induce CS. These include HMDs, Flicker, Field of View (FOV), Lag and Frame Rate, Screen Size, Method of Movement, Calibration, Position Tracking Error, and Head Motion. These factors are grouped in the subthemes of Device and Tracking.

a) *Device:* The Device subtheme consists of factors HMDs, Flicker, FOV, Lag and Frame Rate, and Screen Size.

Head-Mounted Displays (HMDs). When using HMDs, settings, such as contrast, light, exposure length, and operating distance all contribute to straining the visual system. When utilizing a stereoscopic HMD, such as EyePhone LX, in an immersive virtual world for 10 minutes, around 60% of respondents exhibited symptoms, such as eye strain, nausea, and headache, while 20% reported a loss in binocular visual perception [27]. Similar symptoms were reported by 61% of participants following twenty minutes of exposure to immersive virtual material using a DVisor HMD [26].

Technical developments in VR display technology, such as Oculus VR DK1 and Oculus VR DK2, did not significantly reduce CS [20]. Sensory conflict, however, plays a vital role in developing nausea and other symptoms. Body movement, confusion caused by head movement, and poor optical design led to strain-induced ocular pain. [1] recently observed that using HMDs caused more motion sickness than stereoscopic desktop displays. Some users stated that they felt more immersed in an HMD. However, they could only sustain the experience for a short period.

Flicker. Flicker has been extensively researched. The literature [4][12][21][24] suggests that flicker should be avoided at all costs. In a VR scenario, flicker is the brightness fluctuation on video screens that can cause nausea. This oscillation is visually disturbing and affects the user's eye health. When using larger displays, the user is likely to see flicker around the screen's edges. Avoiding flicker is crucial for HMDs with brighter panels and a high refresh rate [12]. Several components of the visual presentation influence flicker perception. The most relevant to visual displays or VR systems are the refresh rate, brightness level, and field of vision [4]. To reduce flicker, the refresh rate must increase as the brightness level increases [21].

Field of view (FOV). The display's horizontal and vertical angular dimensions are known as the FOV [23]. CS is more common in VE situations with a wide FOV than in those with a narrow FOV [7]. This is likely due to enhanced vection caused by higher peripheral retina stimulation from a broad FOV display [8]. A wide FOV also enhances the probability of detecting flicker [11]. This is because the peripheral visual system is more sensitive to flicker. To eliminate flicker, a broader FOV requires a quicker refresh rate [11].

Lag and Frame Rate. Latency is the time elapsed between the user's input and the visible response in a VE display. Frame rate measures how rapidly frames flow through the rendering process. A dip in frame rate might occur in a VR application with sophisticated visuals. Suppose the delay between user input and virtual content production is significant. In that case, there is a considerable risk of developing simulation sickness [11]. A suggested delay is 20 milliseconds; anything greater than 46 milliseconds might cause motion nausea. Companies, such as Oculus, Sony, and Steam stress the significance of virtual content with low latency, responsiveness, and fast frame rates for greater virtual content quality [28].

Screen size. Vection is highest in peripherally moving visual flow fields [7]. As a result, huge displays pose an increased risk of motion sickness. With full flow fields, virtually everyone will feel intense vection. As a general rule, the smaller the visual picture (or display), the lower the likelihood of CS [24]. Laboratory investigations have shown that the danger of vection is limited, with pictures reaching a viewing angle of fewer than 300 degrees [7]. A typical 17-inch computer screen, seen from a distance of 50 cm, contains 340 pixels and will not readily cause vection [7].

b) *Tracking:* The Tracking subtheme consists of the factor's Method of Movement, Calibration, Position Tracking Error and Head Motion. These are discussed below.

Method of Movement. The VR user does not always have control over the character's motions. This lack of mobility can lead to significant problems. To satisfy sensory expectations, movement in a virtual world should be realistic. Inappropriate motions, such as quick tilting, rolling, and waveform motions, should be avoided. Gun sway, head bob, and moving up and down stairs are incorrect movements. According to [11], incorporating motions centered on leaps rather than continuous walks may help to reduce nausea. Uncontrolled user movement outputs should be restricted, such as flipping, falling, or zoom transitions [29].

Calibration. Because of variances in human physical traits, poor calibration exacerbates CS symptoms. Interpupillary distance, for example, the distance between the pupils' centers in both eyes, differs among persons [4]. Because stereoscopic displays require each eye to get a slightly offset image of the virtual world, this offset must be as near to the user's individual interpupillary distance as feasible. Calibration failure might result in greater spatial and temporal distortions, setting the scene for CS due to distorted graphics [4]. As a result, each individual requires suitable calibration. [4] believe that the right size, appropriate focus, and perfect alignment will aid in treating CS.

Position Tracking Error. The VR system's position-tracking error informs the computer about the location of the user's head and, presumably, limbs in the VE [21]. The system uses this data to create a graphical depiction of the user within the VE. If this information needs to be corrected, tracked items may appear in locations where they are not. If the tracked items are part of the user's body, the mismatch between where the graphical representation of the objects appears in the visual display and where the user believes they should appear may bother the user [21]. As a result, the illusion of the simulation may be broken, resulting in sickness-related symptoms, such as dizziness and loss of focus. Finally, location tracking mistakes might generate jitter or oscillations of portrayed body parts, which can be disturbing for users [21].

Head motion. According to [13], adopting a supine posture results in a considerable reduction in CS. They ascribed this to limited head mobility. Head movements are known to be related to CS via Coriolis and pseudo-Coriolis stimulation pathways [13]. When the head is tilted away from the axis of rotation during actual body rotation, Coriolis stimulation occurs [13]. When the head is inclined, apparent self-rotation is caused by visual cues, resulting in pseudo-Coriolis stimulation [13].

3) Software

The characteristics of the software in a VE may impact the probability of CS. The theme is divided into three subthemes: Stabilizing Information, Environment, and Design. Playing Position, Locomotion, Immersion, Sensory Support, and Graphic Realism are contributing factors.

a) *Stabilizing Information:* The stabilizing information subtheme consists of the Playing Position factor.

Playing Position. [13] revealed that a significant reduction in CS occurs when individuals assume a supine position, probably due to limited head mobility. Subjects are expected to be seated or standing in most circumstances within a VE [7]. Because of the lower demands on postural control, sitting patients would experience less illness, according to [7].

b) *Environment:* The Environment subtheme consists of the factor Locomotion.

Locomotion. A vital factor in VE discomfort is accelerated movement or speed. Sensory conflicts that can cause discrepancies occur due to sudden increased or decreased acceleration. Therefore, increasing or decreasing acceleration slowly would result in a pleasant user experience [11]. Rapidly zoomed movements should also be avoided, such as when the visual cones move faster than expected when a user's view is zoomed in [30].

c) *Design:* The Design subtheme consists of factors Immersion, Sensory Support and Graphic Realism.

Immersion. [5] studied the impact of virtual content type on simulation sickness. They noticed that the type of video content, immersive vs. non-immersive, is a critical factor for VE usability. Video content type influenced the contributor's sensitivity to simulation sickness and physiology. Their conclusion was based on the results of a Simulation Sickness Questionnaire (SSQ) and other physiological measures. The lowest SSQ score was recorded for non-immersive virtual content displayed on a television screen, while the highest scores were reported on an HMD with immersive content [5].

Sensory Support. A user might experience higher VR immersion and expect relevant vestibular information after exposure to strong illusions. The system can cause motion sickness if the VR system cannot provide suitable sensory input [31]. Therefore, designing a logical environment in which the players can focus and bind is essential. The user interface elements should be fixed rather than floating, creating an environment with a clear, steady horizon and reference points that users can focus on to minimize sickness. A world with imbalanced or changing backgrounds should be avoided. Designing a virtual world that supports human sensory systems is ideal [31].

Graphic Realism. [12] investigated the results of rendering realistic scenes. Participants who experienced realistic graphic content were prone to a higher level of simulation sickness. The authors also suspect that a sensory discrepancy between the vestibular and visual systems may cause a higher level of discomfort.

B. Answering the research questions

1) What are the causes of cybersickness in the Virtual Reality environment?

A literature review was done in an attempt to understand the reasons why individuals become cyber sick in a VR environment. The Sensory Conflict Hypothesis was the CS theory discovered to be the most often discussed in the literature. According to the hypothesis, illness results from an imbalance between two sensory systems, the vestibular and visual systems. Other research identifies postural instability or the absence of a rest-frame, a fixed reference frame, contributing to CS [41]. However, experiencing motion sickness in VR can potentially lead to postural instability.

2) How can the severity of cybersickness experienced, or susceptibility to it be assessed before, during, or following a session?

To provide an answer to this question, a literature review was conducted. According to the literature there are several objective and subjective techniques to gauge one's vulnerability to or degree of CS. Although the CSQ and VRSQ have shown superior validity for VR, according to the study of [47], the SSQ is still the most often used assessment technique. Examples of one-dimensional scales that let researchers quantify CS while participants are in VR are the FMS and MISC [49]. The MSSQ assesses prior experiences with motion sickness generally, whereas the VIMSSQ assesses susceptibility to CS [49].

In addition to surveys, the physiological condition also reveals how much CS individuals feel. The advantage of physiological data collection is that it can be done throughout the VR experience and is a reliable source of factual information. Measuring the characteristics of gait or postural sway is another technique to obtain objective data. CS was shown to be connected with specific VR headset positional and rotational features by [67].

3) Which factors contribute to Cybersickness during the application of Virtual Reality technologies?

A systematic review was conducted to answer this question. Systematic reviews deliver an orderly, clear means for gathering, synthesizing and evaluating the results of studies on a specific topic or question [32]. The purpose of a systematic review is to minimize the bias linked with solitary studies and non-systematic reviews [32]. A thematic analysis was used to identify the core themes and factors within the selected literature.

Twenty-eight publications were included in the systematic review based on four carefully chosen databases. Twenty-one factors were found to contribute to CS during the application of VR technologies. These factors are Age, Calibration, Duration, Environmental Conditions, Field of View, Flicker, Gender, Graphic Realism, Habituation, Head Motion, Head Mounted Displays, Immersion, Lag and Frame Rate, Locomotion, Method of Movement, Physical Health, Playing Position, Position Tracking Error, Posture, Screen Size, and Sensory Support. As a result, a conceptual model of the factors that lead to CS has been developed.

VI. CONCLUSION

The primary goal of this study was to identify and describe the factors that contribute to CyberSickness (CS) in a Virtual Reality (VR) environment. This was achieved through a SLR and thematic analysis. A model of the factors that lead to CS has been developed to aid in the study of CS in VR.

After conducting this study, it became clear that CS is a multifaceted issue. At present, there is no silver bullet solution. Fortunately, many solutions have been thought of already. Some are more effective than others. We can get closer to a VR experience potentially free of CS by testing and further investigating CS and its underlying mechanisms. One-by-one CS-inducing factors could be reduced if not eliminated.

Limitations of this study are, firstly, only English-language publications were considered. Therefore, data that might be pertinent to the research question but was written in a different language is excluded from this study. Second, just four data sources were utilized to do the SLR; as a result, it's possible that relevant material from other databases was missed. Third, there is a chance that the SLR's search string is not rigorous enough, which might have left out essential themes and factors.

Future researchers and practitioners can evaluate the factors that lead to CS in a VR environment using the model developed. Similar research should also be conducted to support or refute this study's factors and themes.

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