Reducing Cybersickness from Virtual Reality: A Comprehensive Analysis

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***Abstract*—Virtual reality, or VR, has several applications in teaching, entertainment, and business. When utilizing virtual reality, one may get "cybersickness," a simulated sickness. The usefulness of VR devices is severely hampered by Cybersickness (CS). Reducing the unpleasant feeling of CS is crucial to making the most of VR as a medium. A satisfying virtual reality experience results from a combination of technology, software, and user characteristics. There is a lack of comprehensive knowledge about the causes of Cybersickness, the methods for evaluating the degree of Cybersickness, and the variables that influence CS in a virtual reality setting. This research attempts to fill the gap by examining the causes of Cybersickness, how to evaluate it, and identifying and characterizing its contributing variables. A thorough analysis of the literature revealed 21 variables that influence VR CS. Furthermore, a taxonomy of contributing elements to Cybersickness was created so that academics and VR developers could assess them.**

Keywords-virtual reality; simulation sickness; Cybersickness; factors; head-mounted display; comprehensive analysis.

I. Introduction

Due in part to the recent media attention VR has received, it has lately entered the common vernacular [1][2]. In short, virtual reality (VR) provides a "Virtual Environment" (VE) where users interact with a highly lifelike artificial environment composed mainly of three-dimensional computer-generated pictures, sounds, and haptic feedback. VR has been used in several industries, including architecture, construction, and healthcare. Nevertheless, customers are more interested in video games than other VR applications [3]. Head Mounted Displays (HMDs) are the leading technology for virtual environments. Unlike traditional displays, HMDs immerse the user in the virtual environment (VE) by blocking external visual inputs that may disrupt the experience. Such immersive experiences have also been linked to a detrimental side effect called Cybersickness (CS) [3].

Being in a virtual environment (VE) can cause an unpleasant set of symptoms known as "cybersickness," which can last for a few hours or even days [4]. Headache, nausea, and even vomiting are some symptoms [5]. Between 20% and 80% of people are thought to be impacted by CS in some capacity [4]. Even though the condition has long been recognized and studied, CS claims have increased with VR devices' growing popularity [3].

In the worst cases, patients cannot use VR equipment because of the severity of their symptoms. In one case, players complained of feeling sick; thus, developers were obliged to take VR elements out of their games [3]. The symptoms of CS might negatively impact the patient and impede the effectiveness of medical therapy. The user may find even modest symptoms uncomfortable and bothersome.

A. Problem Statement

VR allows users to envision a redesigned three-dimensional environment. That being said, complete sensory awareness is required for maximum effectiveness. Before VR is sufficiently adapted and understood, interactions and visual cues in the VE must be established effectively to be as realistic as feasible [5]. The degree to which the user feels fully involved in the environment may be used to gauge its efficacy [6]. Issues with usability, like CS symptoms, will lessen a user's sense of presence in a virtual environment. Users will not be able to feel the realism of a VE if they encounter difficulties utilizing the environment.

A thorough picture of all the aspects that might lead to CS is necessary for the knowledge base. This study first attempts to uncover the elements leading to CS during VR technology use because of this research gap. Subsequently, a conceptual model that integrates these discovered elements will be developed.

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 research provides an overview of all the proposed variables contributing to CS in a virtual reality setting. It aims to offer practical advice to upcoming and established VR developers on how to lessen CS symptoms to enhance the VR experience. It will also serve as a resource for scholars investigating CS in VR. This will act as a guide for growing the research and connecting it to the factors used. Furthermore, by improving the user experience, it is anticipated that this research would benefit users who encounter CS in VR environments.

This is how the remainder of the paper is structured. The literature on the causes, theories, and measuring techniques of Cybersickness is presented in Section II. The research technique for the Systematic Literature Review (SLR) is presented in Section III. Section IV presents the SLR results, and Section V offers a commentary on the research findings. The work is concluded in Section VI, which also provides suggestions for more 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, and the illness's effects differ from person to person. Many theories about how it began [4][7]. The most discussed hypothesis 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 [8]. Additionally, sensory conflict seems to have an impact on both. However, the sensory conflicts in a car and VR are very different.

When traveling 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 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 [9][10]. However, other research shows vection can happen even when no sickness is present [9]. This shows there is more to the relationship between vection and CS than just a straightforward causal one. In their study, [10], which intended to explore this connection further, discovered that a shift in vection causes sickness. From the standpoint of sensory conflict, it makes sense that CS is more often caused by apparent visual acceleration than 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 [11] are at odds with those of the study by [10]. The vection's strength or fluctuation did not significantly impact VIMS. It is posited that [11] may have yet 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 and self-motion [12][13]. 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.

SCT is explained from a different angle by [14] as an issue of dynamic sensory reweighting. They contend that visual input typically has a more significant weight than vestibular input since multisensory integration favors the most reliable signals; the weight will move more to the visual side when you engage in VR more frequently. CS symptoms may then be reduced with repeated VR exposure [15]. At first, the vestibular system's weighting is higher than the more prominent visual cues, causing significant sensory conflict. However, this sensory weighting shifts with time, and the vestibular system is disregarded, reducing conflict. The Peripheral Visual Field (PVF) controls sensing motion, including vection. In contrast, the Central Visual Field (CVF) is primarily responsible for detecting and identifying objects with the highest density of cones. According to [16], motion in the perceived background causes more vection than motion in the front.

The foreground is the emphasis of the CVF. However, [7] noted that peripheral inputs frequently have a background interpretation. Therefore, the impression of self-motion is more likely to result from motion in the PVF. When placed in the CVF, a motion that traveled laterally increased illness but not vection, whereas a motion that traveled longitudinally (forwards or backward) increased sickness and vection when placed in the PVF.

3) Postural Instability

Postural instability, a notion that [17] first proposed, is another frequently discussed theory. 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 [18][19]. In contrast, others only discovered postural instability due to CS or found no causal relationship [20]. 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 [21]. According to this theory, CS results from the inability to identify or select a stable reference frame, also known as the rest frame, to interpret relative movements, locations, and orientations. The nervous system chooses the rest of the frame from various reference frames and gives it spatial-perceptual data [21]. 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 [16]. In other words, illness is more likely affected by how the user interprets what is moving and what is not based on the degree of competing cues.

Choosing a reference frame is typically an unconscious procedure for most people [21]. However, suppose you have been on a train waiting at a stop adjacent to another train. In that case, you may be familiar with the experience of not having a comfortable resting space. There may be some uncertainty over which train is genuinely moving for a brief period after the other train begins to move. This continues until you see a resting place other than the trains, such as the earth beneath them or other structures. Your mind can thus rationally conclude that the other train, not yours, was moving.

B. Cybersickness Measurement Methods

As covered in the section above, there are only a few well-established theories on CS. Similarly, 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 [22][23]. Both the Cyber Sickness Questionnaire (CSQ) and the Virtual Reality Sickness Questionnaire (VRSQ) published by [22] and [24] can be seen as subgroups of the SSQ. Only nine symptoms remain when the nausea-related symptoms are excluded from the VRSQ.

According to [24], the oculomotor and disorientation components of illness in VR are more critical than the nausea component. They contend that the difference in nausea-inducing effects between VR and simulators is due to the absence of inertial motion. The SSQ, the French version of the SSQ, the VRSQ, and the CSQ were all subjected to a psychometric study [23]. Compared to the SSQ and its French equivalent, they discovered that the VRSQ and CSQ demonstrated more validity. It is conceivable to ask participants to complete an SSQ but then analyze the data using a VRSQ or CSQ because those questions are subsets of the SSQ. A significant drawback is that you may only use the surveys mentioned above before or after a VR experience, owing to their size. As a result, real-time data cannot be obtained using the SSQ, VRSQ, or CSQ.

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 [25]. It is feasible to gauge the time of the motion sickness since participants vocally rate each minute. The FMS, SSQ, and sub-scores also show a substantial correlation in other research [25][26]. 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 a [27] 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 [28] updated the Motion Sickness Susceptibility Questionnaire (MSSQ) 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 [25] since this questionnaire was not designed for CS (or VIMS). [29] Also, due to its length, a condensed version of the VIMSSQ was suggested and examined in another research study.

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 [30]. 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 majority of the literature uses many physiological signals, not just one. [4] recommends using an electrocardiogram (ECG) and blood pressure in their review. Still, [31] recommends the most accurate assessment technique for galvanic skin response. Other potential techniques include eye tracking, heart rate, breathing, and cutaneous thermoregulatory vascular tone [2][30]. [8] discovered that autonomic arousal was primarily responsible for variations in heart rate and breathing. Measuring the physiological status makes it possible to create a closed-loop system, which is a significant advantage.

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 [20][32]. Based on physiological data, such as heart rate, breath rate, heart rate variability, and galvanic skin reaction, [32] created an entirely closed-loop system. Based on the determined amount of sickness, the field of view (FOV) reduction or Gaussian blurring was applied, 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, 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 [33]. [34] 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, 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 [18][35][36]. After analyzing their data, [35] identified the precise postural sway characteristics that might predict VIMS. According to the findings, those who reported feeling worse had more circular postures (as opposed to elliptical) and a higher frequency of forward/backward oscillations. According to each participant's postural sway, [36] 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 tested by [37] 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 [38]. 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 uses an 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*" [39]. Simply put, an SLR is a review of primary studies. This study follows the SLR guidelines by [39]: 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 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 describe the factors that lead to Cybersickness in a VR setting.
- 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 the 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) Process for conducting the review

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

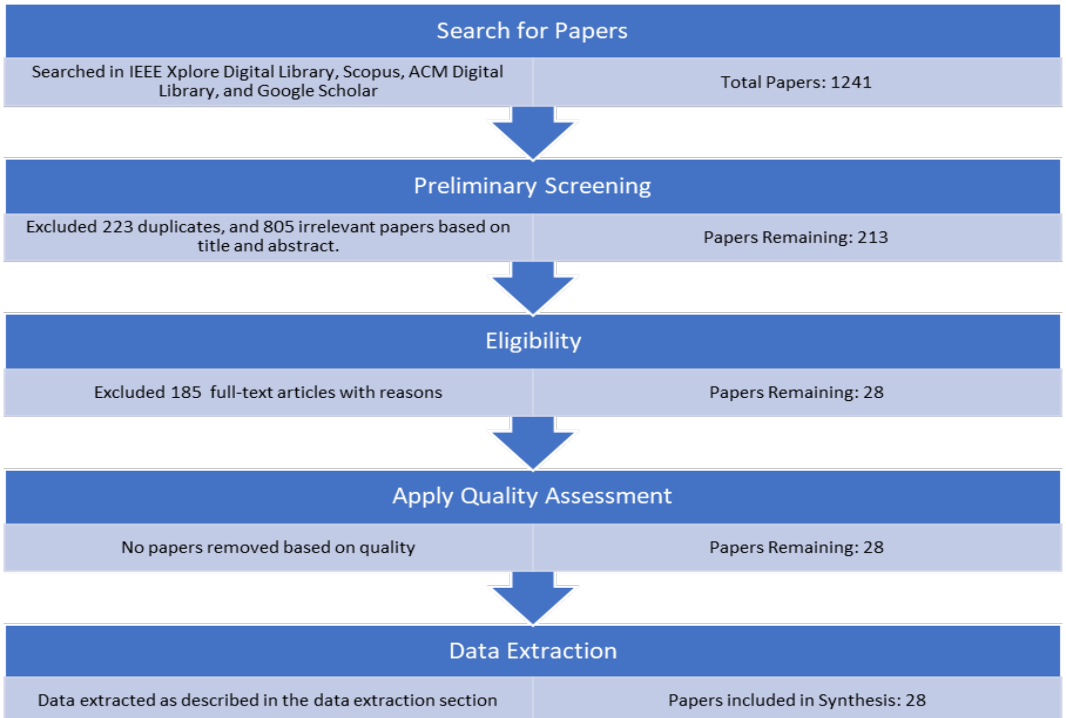

Figure 1. Summarized process for conducting the systematic review.

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 [39]. 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 follow a research process and describe the data analysis techniques?

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 ratings are displayed in the results section.

C. Data Extraction

The data extraction was carried out on 28 papers included in the SLR. After that, 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 called codes, were carefully investigated to group them into common themes. All the pertinent information that helped answer 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 central concept. Google Sheets were used to extract data for the thematic analysis.

IV. RESULTS

A. Search Results

The articles listed in the source selection section were looked at in four databases, which include 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%. 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

As mentioned earlier, four questions were used to assess the quality of the selected literature. Most papers were of good quality, with an average score of 3.75 out of 4. No paper scored below 3 (see Table II).

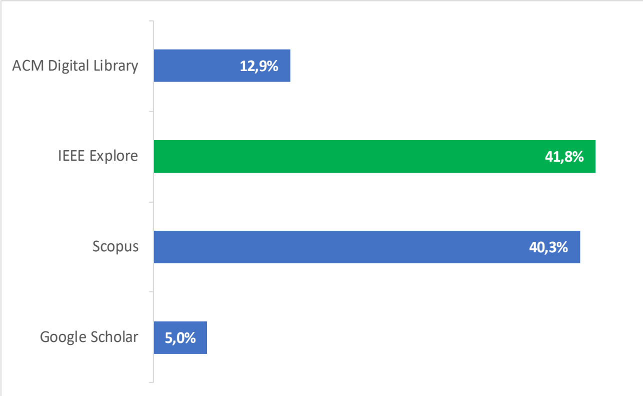

Figure 2. Database articles percentage distribution.

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 contributed 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 analyzed to identify any additional relationships to help categorize them. Categorizing the factors helps to understand the more significant themes and gives more profound 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 III lists the synthesized themes, subthemes, and the contributing CS factors. A taxonomy of the contributing factors to Cybersickness is shown in Figure 3.

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 an address to 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 is discussed below. These factors are grouped into Demographics, Experience, and Physical Attributes.

TABLE I. VIRTUAL REALITY CYBERSICKNESS FACTORS WITH SOURCES

Factor	Sources
Habituation	[40]-[43]
Duration	[5][33][40]-[42][44][45]
Environmental conditions	[46]
Physical Health	[5][41][47]-[49]
Posture	[5][45][50]
Gender	[5][33][40][42][46][47][51]-[53]
Age	[5][33][40][47][53][54]
Field of View	[33][40][41][44][55]
Flicker	[5][33][53][56]
Screen size	[40][56]
Head-mounted displays	[2][6][31][33][42][46][56]-[58]
Lag and Frame Rate	[44][59]
Method of movement	[56][60]
Calibration	[5]
Position Tracking error	[53]
Head motion	[45]
Playing position	[40]
Locomotion	[33][40][44][61]
Immersion	[33][40][62]
Sensory support	[62]
Graphic Realism	[33]

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

Age. According to the literature, younger persons are more resistant to simulation sickness [33]. After age 40, people's vestibular perception threshold, or the lowest signal recognized, decreases, rendering them more susceptible to simulation sickness [47]. [54] discovered changes in the postural balance between young and middle-aged test participants. Furthermore, postural balance deteriorates as people age, which can contribute to illness.

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. [52] 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.

TABLE II. QUALITY EVALUATION ANSWERS

No	Citation	Q1	Q2	Q3	Q4	Score
1	[56]	Yes	Yes	Yes	Yes	4
2	[59]	Yes	Yes	Yes	Yes	4
3	[44]	Yes	Yes	Yes	Yes	4
4	[33]	Yes	Yes	Yes	Yes	4
5	[62]	Yes	No	Yes	Yes	3
6	[6]	Yes	Yes	Yes	Yes	4
7	[58]	Yes	Yes	Yes	Yes	4
8	[57]	Yes	Yes	Yes	Yes	4
9	[42]	Yes	Yes	Yes	Yes	4
10	[46]	Yes	Yes	Yes	Yes	4
11	[52]	Yes	Yes	Yes	Yes	4
12	[54]	Yes	No	Yes	Yes	3
13	[60]	Yes	Yes	Yes	Yes	4
14	[53]	Yes	Yes	Yes	Yes	4
15	[2]	Yes	Yes	Yes	Yes	4
16	[40]	Yes	No	Yes	Yes	3
17	[31]	Yes	Yes	Yes	Yes	4
18	[61]	Yes	Yes	Yes	Yes	4
19	[51]	Yes	Yes	Yes	Yes	4
20	[43]	Yes	Yes	Yes	Yes	4
21	[5]	Yes	No	Yes	Yes	3
22	[49]	Yes	No	Yes	Yes	3
23	[50]	Yes	Yes	Yes	Yes	4
24	[41]	Yes	Yes	Yes	Yes	4
25	[55]	Yes	Yes	Yes	Yes	4
26	[47]	Yes	No	Yes	Yes	3
27	[45]	Yes	No	Yes	Yes	3
28	[48]	Yes	Yes	Yes	Yes	4

[46] 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 center of one's eyes). They also propose redesigned VR headsets with adjustable interpupillary distance to decrease CS in women.

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

Habituation. According to [42], 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 [46].

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 [33][40][41][44]. 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 [44].

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

TABLE III. 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

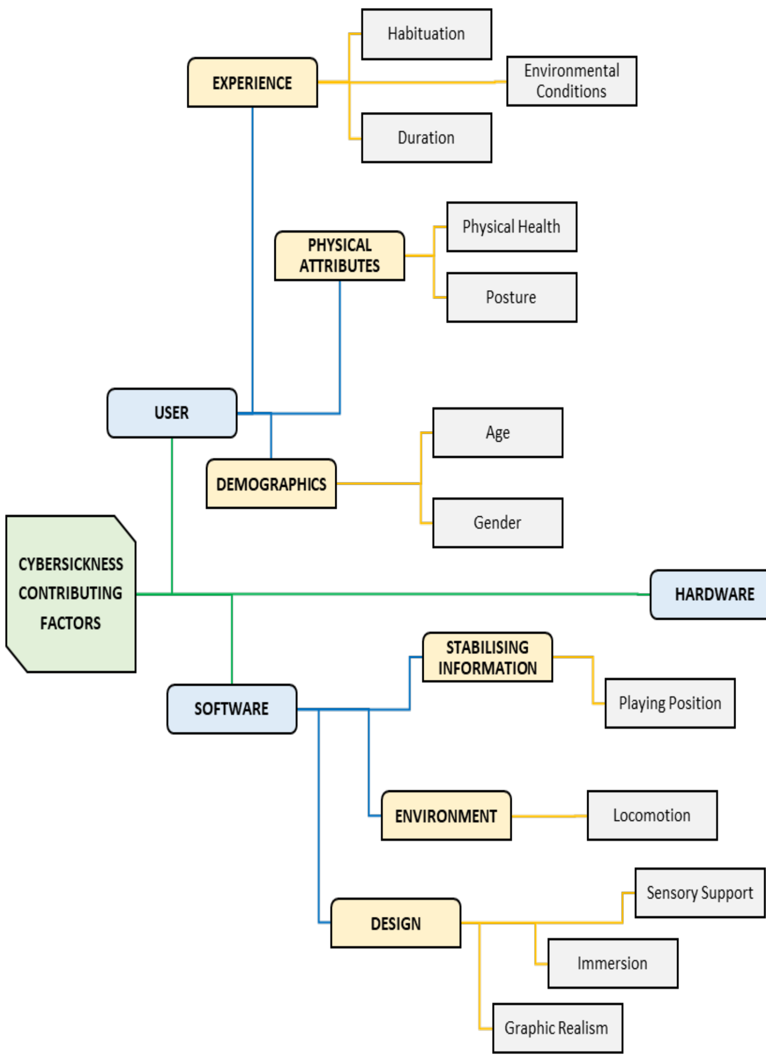

Figure 3. Taxonomy of Cybersickness contributing factors.

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, tired, or is sleep deprived, it is best to avoid a virtual environment since their symptoms may aggravate [44].

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 [5][45][50].

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 includes factors such as HMDs, Flicker, FOV, Lag and Frame Rate, and Screen Size.

Head-Mounted Displays (HMDs). When using HMDs, contrast, light, exposure length, and operating distance 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 [58]. Similar symptoms were reported by 61% of participants following twenty minutes of exposure to immersive virtual material using a DVisor HMD [31].

Technical developments in VR display technology, such as Oculus VR DK1 and Oculus VR DK2, did not significantly reduce CS [52]. 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, it was 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 [5][33][53][56] 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. The user will likely see flicker around the screen's edges when using larger displays. Avoiding flicker is crucial for HMDs with brighter panels and a high refresh rate [33]. 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 [5]. To reduce flicker, the refresh rate must increase as the brightness level increases [53].

Field of View (FOV). The display's horizontal and vertical angular dimensions are known as the FOV [55]. CS is more common in VE situations with a wide FOV than those with a narrow FOV [40]. This is likely due to enhanced vection caused by higher peripheral retina stimulation from a broad FOV display [41]. A wide FOV also enhances the probability of detecting flicker [44]. This is because the peripheral visual system is more sensitive to flicker. To eliminate flicker, a broader FOV requires a quicker refresh rate [44].

Lag and Frame Rate. Latency is the time 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 [44]. A suggested delay is 20 milliseconds; anything more substantial 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 [59].

Screen size. Vection is highest in peripherally moving visual flow fields [40]. As a result, huge displays pose an increased risk of motion sickness. With full-flow fields, virtually everyone will feel intense vection. Generally, the smaller the visual picture (or display), the lower the likelihood of CS [56]. Laboratory investigations have shown that the danger of vection is limited, with pictures reaching a viewing angle of fewer than 300 degrees [40]. A typical 17-inch computer screen, seen from a distance of 50 cm, contains 340 pixels and will not readily cause vection [40].

b) *Tracking:* The Tracking subtheme comprises 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, should be avoided. Gun sway, head bob, and moving up and down stairs are incorrect movements. According to [44], 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 [60].

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 [5]. Because stereoscopic displays require each eye to get a slightly offset image of the virtual world, this offset must be as near the user's interpupillary distance as feasible. Calibration failure might result in greater spatial and temporal distortions, setting the scene for CS due to distorted graphics [5]. As a result, each individual requires suitable calibration. [5] believes 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 [53]. The system uses this data to depict the user within the VE visually. 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 [53]. 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, disturbing users [53].

Head Motion. According to [45], 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 [45]. Coriolis stimulation occurs when the head is tilted away from the axis of rotation during actual body rotation [45]. When the head is inclined, apparent self-rotation is caused by visual cues, resulting in pseudo-Coriolis stimulation [45].

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. [45] revealed that a significant reduction in CS occurs when individuals assume a supine position, probably due to limited head mobility. In most circumstances, subjects are expected to be seated or standing within a VE [40]. Because of the lower demands on postural control, sitting patients would experience less illness, according to [40].

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 cause discrepancies occur due to sudden increased or decreased acceleration. Therefore, increasing or decreasing acceleration slowly would result in a pleasant user experience [44]. 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 [61].

c) *Design:* The Design subtheme comprises Immersion, Sensory Support, and Graphic Realism.

Immersion. [6] studied the impact of virtual content type on simulation sickness. They noticed that the kind of video content, immersive vs. non-immersive, is critical 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 [6].

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 [62]. 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 [62].

Graphic Realism. [33] investigated the results of rendering realistic scenes. Participants who experienced realistic graphic content were prone to higher simulation sickness. The authors also suspect a sensory discrepancy between the vestibular and visual systems may cause more 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 cybersick 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 [17]. 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?

A literature review was conducted to provide an answer to this question. According to the literature, several objective and subjective techniques can be used 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 [23], 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 [25]. The MSSQ generally assesses prior experiences with motion sickness, whereas the VIMSSQ assesses susceptibility to CS [25].

In addition to surveys, the physiological condition 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 [43].

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 [63]. The purpose of a systematic review is to minimize the bias linked with solitary studies and non-systematic reviews [63]. 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 contributed 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

This study's main objective was to find and characterize the variables that lead to Cybersickness (CS) in a virtual reality (VR) setting. Thematic analysis and an SLR were used to accomplish this. A model of the contributing elements to CS has been created to facilitate the investigation of CS in VR.

It became evident from doing this analysis that CS is a complex problem. There isn't a magic bullet answer available right now. Thankfully, a lot of options have previously been considered. Certain ones work better than others. By testing and learning more about the underlying mechanics of CS, we can move closer to a VR experience that may be devoid of it. Individual CS-inducing elements might be minimized if not completely removed.

The first limitation of this study is that it only looked at articles written in English. Thus, this analysis does not include information published in a language other than English that may be relevant to the research issue. Second, there's a chance that pertinent information from additional databases was overlooked because the SLR only used four data sources. Third, it is possible that the SLR's search criteria were not strict enough, leading to omitting important themes and variables.

With the established model, future scholars and practitioners may assess the conditions that give rise to CS in a virtual reality setting. The elements and topics of this study should be further investigated and supported or refuted by similar studies.

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