IEEE Access
Multidisciplinary ⋮ Rapid Review ⋮ Open Access Journal

Received 23 May 2024, accepted 23 June 2024, date of publication 26 June 2024, date of current version 12 July 2024.

Digital Object Identifier 10.1109/ACCESS.2024.3419589

METHODS

Adaptation and Validation of the Simulator Sickness Questionnaire to Portuguese (SSQp) Based on Immersive Virtual Reality Exposure

GUILHERME GONÇALVES[1,2], **MIGUEL MELO**[1,2], **CARLOS SERÔDIO**[1,3], **RUI SILVA**[1,4], **AND MAXIMINO BESSA**[1,2]
[1]Department of Engineering, University of Trás-os-Montes e Alto Douro, 5000-801 Vila Real, Portugal
[2]Institute for Systems and Computer Engineering, Technology and Science, 4200-465 Porto, Portugal
[3]ALGORITMI Center, Universidade do Minho, 4800-058 Guimarães, Portugal
[4]Department of Economics, Sociology and Management, Centre for Transdisciplinary Development Studies, 5000-801 Vila Real, Portugal

Corresponding author: Guilherme Gonçalves (guilhermeg@utad.pt)

This work is financed by National Funds through the Portuguese funding agency, FCT - Fundação para a Ciência e a Tecnologia, within project UIDB/50014/2020.

ABSTRACT Cybersickness refers to the negative symptoms caused by exposure to a Virtual Reality (VR) experience. The literature is consensual that cybersickness is a key factor in an experience, as the non-existence of cybersickness provides an optimal virtual experience. Thus, it is of utmost importance to evaluate cybersickness when assessing VR applications to understand the impact of this factor on the user experience and, ultimately, on the VR application viability. However, there is a lack of Portuguese instruments to evaluate this variable. To tackle this, this aimed to translate and validate the Simulator Sickness Questionnaire (SSQ) to Portuguese so it can be used with the Portuguese population and maintain its psychometric properties. The new instrument was validated using a sample of 603 Portuguese subjects aged between 16 and 79. Based on the observed results, the obtained theoretical model shows that the Portuguese version of the SSQ is valid for properly evaluating cybersickness in VR experiences with Portuguese samples.

INDEX TERMS Virtual reality, cybersickness, simulator sickness, immersive, questionnaire, validation, Portuguese.

I. INTRODUCTION

Virtual Reality (VR) technologies have become widespread worldwide, primarily due to their capability to allow their users to experience virtual worlds in such an immersive way that perceptually, they begin to act as if it was real, even if they know it is not [1]. This is primarily due to the capability of immersive VR to isolate users from real-world stimuli while providing them with synthesized stimuli through a highly controlled and manipulable environment that can potentially transport individuals to new ‘‘realities’’, both cognitively and perceptually. The extent to which users are isolated from the real world is defined by the level of immersion [2], [3]. For example, a non-immersive VR system, such as a regular gaming console connected to a conventional display, provides low isolation from real-world stimuli. This is due to individuals still being able to view, hear and overall sense the real world mixed with the virtual stimuli from the display. Conversely, in an immersive VR system, such as Head Mounted Displays (HMD), certain stimuli can be fully isolated from the world outside the virtual experience. The most notorious sense isolated is vision. While wearing HMDs, all users can see is the synthesized visual stimuli from the HMD screens right in front of their eyes. To provide depth perception, immersive VR systems commonly recur to stereoscopy. This technique allows each eye to see a

The associate editor coordinating the review of this manuscript and approving it for publication was Tai-Hoon Kim.

slightly different perspective of the virtual environment (due to the distance between eyes), the same way we perceive depth in the real world. Similarly, auditory feedback can also be isolated through the use of, for example, headphones. Likewise, other senses can be isolated so that users only receive the stimuli referring to their virtual experience to experience a more realistic virtual experience [4]. These factors lead VR users to become fully immersed in the virtual experience and unaware of their surroundings, mainly since the proprioception system (i.e., the ability to perceive our body position, movement, and orientation in space) loses its capability to track the body position in the real world due to the lack of the real-world multisensory stimuli. As virtual stimuli replace real-world stimuli, the proprioception system starts relying on the virtual stimuli, affecting the body's reactions and behaviours.

The human body has evolved to process sensory stimuli in a particular manner, and with ongoing life experiences, this knowledge is reinforced through continuous feedback mechanisms. In normal circumstances, such as in the real world, the stimuli the body receives are coherent with one's expectations of how the real world works. To illustrate, if we walk forward, we also see ourselves walking forward as the surrounding environment is ''left behind''. Before crossing a road, we can hear if cars are coming from the left or right and can confirm this information visually, and vice-versa. Another example is when we are inside a car accelerating, we feel the g-forces on the body and visually confirm that we are accelerating. As a result, individuals develop an understanding of how the real world works based on their perceptual experiences and interactions with the environment. However, sensory feedback inconsistent with our body's evolved understanding of the environment can lead to conflicts between sensory systems, resulting in various physiological and perceptual reactions.

Immersive VR enables a highly controlled and manipulable environment that can potentially transport individuals to new ''realities'', both cognitively and perceptually, which can be both an advantage or a significant challenge. Since it is possible to manipulate and create new ''realities'' in immersive VR, creating virtual experiences compatible with individuals' real-world understanding it is of utmost importance to create. The regular feedback loop between the body and the surrounding environment can be disrupted if the virtual stimuli do not present synchronicity or coherency. In immersive VR, for instance, the relationship between moving one's head and receiving timely and coherent visual feedback is critical. For example, there is a perceptual mismatch when moving the head to the right and the corresponding visual stimuli lags. In addition to synchronicity, coherence is also a key factor. For example, it is possible to create a situation in which an individual hears a sound from the left and visually perceives an object approaching from the right, which is a physically impossible scenario in the real world (assuming an individual is healthy), or riding a roller coaster, visually see ourselves moving up and down at various speeds but with no haptic feedback as we remain stationary in a regular chair. This example illustrates how VR can disrupt the usual way the human body perceives and integrates sensory feedback, creating perceptual conflicts not present in the physical world. This conflict can disrupt the normal human body and induce Cybersickness, i.e., adverse symptoms during (or after) a VR experience, such as nausea, ocular discomfort and disorientation [5].

Cybersickness can ensure or impede the proper adoption and use of a VR application, and consequently, it is a highly researched factor. It is known that VR applications are more likely to succeed if they do not elicit cybersickness symptoms [6]. For example, research has shown that cybersickness negatively correlates with the sense of presence, a commonly used metric to evaluate virtual experiences [7]. Additionally, and to a certain extent, cybersickness can negatively impact users' cognitive performance [8] and reaction times [9]. However, if users consistently experience cybersickness symptoms, it may lead to negative symptoms and reluctance to engage with VR, resulting in reduced adoption rates and decreased usage. Therefore, researchers and developers are working to understand better and mitigate the causes of cybersickness to ensure that users can fully benefit from the immersive potential of VR technology. This paper contributes to the literature by presenting an adapted and translated version of the well-established SSQ to Portuguese that will enable Portuguese-based studies to take advantage of a properly validated instrument to assess the key variable cybersickness when evaluating VR applications, allowing them to understand better the performance of the evaluated VR applications and generating new knowledge regarding the factors that can affect cybersickness and how to mitigate it.

II. LITERATURE REVIEW

Cybersickness is a key aspect to consider when delivering a VR experience since it can compromise the success of the VR application. Thus, beyond evaluating cybersickness, it is crucial to understand what cybersickness actually entails. This section discusses theories related to the origin of cybersickness, the factors influencing it, its implications, and the instruments used for evaluation.

A. THEORIES OF THE ORIGIN OF CYBERSICKNESS

Several early theories have been proposed to explain the origin of cybersickness [5], [6], [10], but one of the oldest and most widely accepted is the Sensory Conflict Theory [11]. This theory suggests that conflicting sensory inputs, such as visual and vestibular cues, can cause cybersickness symptoms because the body cannot reconcile the sensory conflict and determine how to respond. The theory can explain the common underlying cause of motion sickness (i.e., sickness due to an individual's sensory movement through their vestibular system without visual cues) and cybersickness. Under this theory, Cybersickness has the same underlying cause as motion sickness.

The Poison Theory is another theory to explain why cybersickness symptoms arise from an evolutionary perspective [12]. The Poison Theory suggests that when the body ingests a toxic substance, symptoms like nausea and discomfort arise as a warning to expel the harmful contents and increase survival chances. In the case of virtual experiences that cause sensory mismatches, the brain may interpret the situation as the ingestion of something dangerous, triggering similar symptoms as a protective mechanism.

The Postural Instability Theory [13] suggests a different approach. It proposes that cybersickness can be attributed to the inability of the body to maintain postural stability (one's ability to maintain a stable and balanced upright posture against external forces such as gravity). It relies on systems such as the vestibular, visual and somatosensory systems to keep this balance [14], [15]. The conflicting sensory input may result in postural instability, causing the body to react in ways that are not optimal for maintaining balance and stability. The longer individuals are in a state of postural instability, the higher the chance of cybersickness.

While the exact origin of cybersickness remains a subject of ongoing research, it is known that multiple factors can influence its occurrence. These factors can be divided into individual factors and technological as explained in the following section.

B. FACTORS OF CYBERSICKNESS

To understand how to mitigate cybersickness, it is important to understand the factors contributing to it. LaViola [5] discussed factors known to cause cybersickness and segmented them into two categories: individual factors (gender, age, illness, position in the VE) and technological factors (position tracking error, lag, flicker). Some years later, Davis et al. [10], in their systematic review on cybersickness, identified several factors related to cybersickness and divided them into three categories: individual (e.g. age, gender, illness, and posture), device (e.g., lag, flicker, calibration, and ergonomics) and task (e.g., control and duration). A more recent study by Chandra et al. [6] put together a series of factors related to cybersickness and divided them into user factors (age, gender, exposure, control), displays factors (HMD, large and desktop displays), and VR content type (immersion, graphic realism, field of view, and design). Next, the factors that cause cybersickness are presented following LaViola [5] categorization: individual and technological factors. This categorization was adopted as it comprehends all the subsequent categorizations straightforwardly.

1) INDIVIDUAL FACTORS

Among the individual factors, the most highlighted in the literature are age, gender, illness, posture, and exposure to VR.

Numerous studies in the existing literature indicate that age plays a significant role in contributing to cybersickness. Davis et al. [10] and LaViola [5], based on Reason and Brand [11] and Kolasinski work [16] work, pointed out that cybersickness susceptibility is the highest from 2 to 12 years, decreasing quickly from 12 to 21 years and that around 50 years of age cybersickness is unlikely to exist. However, in their literature review, Chandra et al. [6] state that younger individuals should be less likely to suffer from cybersickness, whereas older people would be more susceptible. The same results were evidenced by Petri et al. work [17] where participants above 60 years were the most affected by cybersickness contrary to the age group of 18 to 60.

Gender is also known to affect cybersickness, with studies indicating that females are more prone to these symptoms than males [5], [10], [16], [18]. However, the underlying cause is still discussed. For instance, Biocca [19] suggested that males tend to be more reluctant to report these symptoms. Some studies suggest that the differences may be attributed to females having a wider field of view, making them more susceptible to flickering stimuli or potentially influenced by female hormones [16]. However, more recent studies indicate that gender differences in cybersickness may have an underlying technological basis. In a study by Stanney et al. [20], it was demonstrated that the primary factor contributing to cybersickness in females was improperly adjusting interpupillary distances in head-mounted displays (HMDs).

Individuals that suffer from illness could become more predisposed to cybersickness [5], [10]. Fatigue, Hangovers, the Flu, or other illnesses could influence the sensitivity to cybersickness. Additionally, certain medications could introduce dizziness or disorientation as side effects, which worsens the situation.

The occurrence of cybersickness can also be influenced by postural factors, which are associated with the position of users during the simulation. These factors align with the principles of the postural stability theory [13] in understanding the relationship between posture and cybersickness. Seated individuals should suffer less from cybersickness as their current positions require fewer demands on postural control [5], [10]. This makes walking and running situations of high postural control demand and thus a higher probability of cybersickness.

The level of individuals' exposure to VR can also impact their susceptibility to cybersickness.

Studies have revealed different findings related to how cybersickness is affected by prolonged exposure to a single virtual experience [6], [10], [21], [22], [23]. For example, Melo et al. [24] found no significant association between exposure time (1 to 9 minutes) and cybersickness. Similarly, Petri et al. [17] observed no significant differences in cybersickness between 10 to 20 minutes of exposure time in participants aged 18 to 60. Conversely, Risi and Palmisano [25] reported results that supported a positive correlation between exposure time and cybersickness.

Other sources also indicate that exposing users to brief sessions of VR multiple times may facilitate adaptation and potentially reduce the occurrence of cybersickness [5], [16], [21], [23], [25].

2) TECHNOLOGICAL FACTORS

The most common technological factors that elicit cybersickness are the degree of control over the VR experience, the lag/latency, flickering, calibration of the sensory stimuli, tracking, and ergonomics.

According to the literature, individuals' degree of control over the virtual environment can impact cybersickness. When users have higher control and can expect appropriate reactions to their actions, the likelihood of experiencing cybersickness is reduced [6], [16], [26], [27].

For example, Sharples et al. [26] conducted a comparison between passive movement (controlled by the researcher) and active movement (allowing subjects to move freely). The study revealed that active control resulted in lower levels of cybersickness.

Peripheral vision is particularly sensitive to optical flow patterns, so a wider field of view intensifies the vection (illusion of self-motion [5], [28]) experience. leading to a sensory mismatch described in the Sensory Conflict Theory [5]. Additionally, faster flow patterns are interpreted as faster movement, further influencing self-motion perception.

In the literature, lag/latency is recognized as a technological factor influencing the likelihood of experiencing cybersickness [5], [6], [10], [16], [29], [30].

Higher latency is usually followed by higher chances of cybersickness. However, there are thresholds upon which latency does not seem to significantly affect cybersickness, but the literature is not concise in what those values are. On top of that, they seem to vary depending on the stimulus and type of experience [30].

Flicker is widely recognised as a factor that can contribute to eye strain, distraction, and ultimately cybersickness [5], [6], [10], [16]. The presence of flicker is influenced by both the field of view and refresh rate of the display device [5], [31]. The human peripheral vision is more sensitive to flicker compared to the fovea [32]. Consequently, when the display offers a wider field of view, individuals have a higher chance of perceiving flickering in addition to vection. Displays refresh their images at specific intervals, known as the "refresh rate". At a certain point called the "critical flicker fusion rate" [16], [31], [32], the images are perceived as a continuous signal, eliminating flicker. However, the critical flicker fusion rate can vary from person to person [5], [16]. Rebenitsch and Owen [23] recommended reducing the field of view for highly susceptible participants, which could help reduce flicker and vection. Therefore, when using displays with a wider field of view, having a higher refresh rate is essential to surpass the individual's flicker fusion rate.

Calibration is one of the most important steps before experiencing an immersive virtual environment. Lack of proper calibration can result in visual distortions as well as desynchronization between sensory stimuli, resulting in cybersickness [10], [16], [20], [21]. For example, and as discussed before, poor calibration of the interpupillary distance was found to be one of the reasons for differences in cybersickness between genders. McCauley and Sharkey [21] also argued that commercially available VR systems might not benefit from the level of calibrations done at professional/research simulators. Thus, cybersickness might be more prevalent in these systems.

Immersive VR systems rely on tracking the user's body to calculate the display image and other components. The inaccuracy of tracking devices may lead to cybersickness [5]. If head tracking is lost, the image displayed stops being coherent with the user's real head movement, and thus, a sensory conflict arises, leading to postural stability.

According to the literature, evidence indicates that poor ergonomics can impact cybersickness [10], [21]. For instance, the weight of VR headsets, as well as strap tightness and accumulated heat, can lead to discomfort [33]. Additionally, wires in a VR setup can interfere with the participant's experience, requiring them to move to avoid the wires. This interference could affect postural stability and, consequently, the likelihood of experiencing cybersickness. However, a recent study suggested that the distinction between tethered (wired) and wireless VR setups may not significantly impact cybersickness [34].

C. IMPLICATIONS OF CYBERSICKNESS

Cybersickness encompasses a range of symptoms that can vary in intensity, directly impacting an individual's comfort. These symptoms can compel users to take frequent breaks, adjust their posture to alleviate cybersickness, or even avoid using the technology altogether. For instance, VR simulators have found extensive applications in professional training across diverse fields. However, if users experience cybersickness during simulator training, it can significantly impact their performance, consequently undermining the efficacy of such simulators. Ensuring user comfort and minimizing cybersickness becomes paramount to maximizing training outcomes. Moreover, cybersickness can be a confounding variable, potentially influencing study results. Recognizing this, many researchers meticulously track and monitor cybersickness to account for its potential effects and minimize their impact on study outcomes [2], [35], [36], [37]. It is important to note that cybersickness symptoms can persist during the VR experience and after its conclusion. This raises concerns on how users could be affected afterwards [9], [38]. Therefore, when designing immersive virtual experiences, careful attention should be paid to content and technology to mitigate the risk of cybersickness and promote user well-being. Strategies such as directing attention to the central visual field to reduce the impact of vection in peripheral vision [39] and implementing low cybersickness impact locomotion methods [40] can contribute to creating more comfortable and enjoyable VR experiences. The various implications of cybersickness, such as its impact on user comfort, performance in VR training, study validity, and user health, can collectively influence the overall adoption of VR technology. Consequently, understanding cybersickness comprehensively becomes essential, including its development, effects on users, and mitigation strategies.

Therefore, it is crucial to employ validated methods to track cybersickness, enabling research to delve into its underlying mechanisms and explore effective measures for its reduction.

D. MEASURES OF CYBERSICKNESS

The assessment of cybersickness can be conducted through the utilization of objective metrics, subjective metrics, or a combination of both approaches in a mutually reinforcing manner. Objective evaluation of cybersickness entails the examination of physiological indicators such as heart rate variability, galvanic skin response, or muscular tension, as well as the analysis of postural stability and reaction time. On the other hand, subjective metrics rely on users' direct feedback, commonly obtained through interviews or questionnaires administered after exposure to VR experiences. Among these methods, questionnaires have emerged as the most widely adopted instrument for assessing cybersickness [2], [35].

Over time, various cybersickness questionnaires have been introduced, including the Simulator Sickness Questionnaire (SSQ) [41], the Motion Sickness Assessment questionnaire (MSAQ) [42], the Fast Motion Scale (FMS) [43], and the VR Sickness questionnaire (VRSQ) [44]. Additionally, there is the option of utilizing custom-made questionnaires. However, it should be noted that the psychometric properties of these custom-made questionnaires are not adequately validated, rendering them less reliable compared to appropriately validated questionnaires.

The SSQ is one of the earliest and most widely used questionnaires for assessing cybersickness in current research [2], [35], [41]. The SSQ was initially developed based on the Pensacola Motion Sickness questionnaire, introduced in 1964 to evaluate motion-induced sickness experienced during zero-gravity maneuvers [45]. The Pensacola questionnaire was designed to assess functional symptoms among individuals exposed to flight simulators during aviation training in Pensacola, Florida, which is renowned for its naval and aviation training activities. It initially focused on measuring general discomfort, pallor, sweating, nausea, and vomiting symptoms, presenting a unidimensional structure. Expanding upon this questionnaire, the SSQ introduced 16 items that assess three distinct subscales: nausea, oculomotor discomfort, and disorientation. Each item describes a symptom associated with exposure to a virtual experience, and respondents rate the severity of these symptoms on a scale ranging from 0 (none) to 4 (severe).

Another valuable instrument for evaluating cybersickness is the MSAQ introduced by Gianaros et al. in 2001 [42]. The development process of this instrument began with the participation of 67 students who were asked to provide ten different adjectives that could describe the sensation of ''motion sickness''. They were then prompted to rank these adjectives based on their ability to describe their own experiences with motion sickness. Through this process, an initial list of 87 adjectives was generated. Three researchers independently analyzed the list to identify synonymous adjectives, producing a refined set of 71 items.

Subsequently, the top 34 items were selected to form the questionnaire, administered to a separate group of 747 students in a second study. Participants were asked to rate how well each item described their experience of motion sickness on a scale ranging from 0 (not at all) to 3 (very). Items that scored below 1 by at least 50% of the sample or were deemed ambiguous were eliminated. This resulted in the removal of 14 items from the questionnaire.

A principal axis factor analysis with Promax rotation was performed to determine potential subscales within the instrument. This analysis identified four distinct subscales corresponding to the affected systems: gastrointestinal, central, peripheral, and sopite-related (associated with sopite syndrome characterized by drowsiness and mood changes). A confirmatory analysis was subsequently conducted, leading to the exclusion of four additional items. The final version of the MSAQ consists of 16 items that accurately capture the multifaceted aspects of motion sickness experiences.

The FMS is another tool that enables the assessment of cybersickness resulting VR experiences. Previous research has established a significant correlation between the FMS and the SSQ [43]. However, there are notable distinctions between the FMS and the SSQ. The FMS is administered verbally to participants during their engagement in the VR experience itself. It involves participants rating their level of cybersickness on a scale ranging from 0 (no cybersickness) to 20 (frank sickness) at predetermined intervals (e.g., every 2 minutes of the VR session). Despite its usefulness, the FMS questionnaire possesses certain drawbacks. Firstly, its questions can be considered vague, potentially leading to subjective interpretations by participants. Additionally, the FMS questionnaire can be intrusive in nature, requiring participants to provide feedback during the VR experience. This aspect of the questionnaire may disrupt participants' sense of presence and immersion within the VR environment.

VRSQ, developed by Kim et al. in 2018 [44], is a more recent tool designed to evaluate cybersickness following exposure to VR experiences. The foundation of this instrument lies in the widely used SSQ. An exploratory and confirmatory factor analysis was conducted using data from a case study to assess the suitability of the SSQ for evaluating cybersickness in the context of VR headsets. The results of these analyses led to the removal of 7 out of the original 16 items from the SSQ. Consequently, the VRSQ comprises a shortened version of the SSQ, focusing on two subscales: oculomotor discomfort and disorientation. Despite its brevity, the VRSQ has not gained as widespread adoption in the literature as the original SSQ [2], [35]. This can be attributed to the original SSQ being a more comprehensive instrument.

III. METHODS

This paper focuses on contributing to the literature with a valid instrument that enables VR studies with Portuguese samples to be conducted. For this purpose, we present an adaptation and validation of the SSQ to the Portuguese language following the original model scales.

A. QUESTIONNAIRE ADAPTATION

The SSQ is a self-report questionnaire created to assess global cybersickness through sixteen items that assess overall cybersickness, nausea, oculomotor discomfort, and disorientation). All questions were presented with the corresponding anchors in the original four-point scale format.

The adaptation to the Portuguese language (pt-pt) followed the translation/back-translation method proposed by Brislin [46] and Hambleton and Zenisky [47]: four bilingual experts and PhDs: two with expertise in psychometry and the other two from the field of computer science, with expertise in VR. The first step was to translate the original questionnaire into Portuguese. Then, the translated questionnaire was back-translated to English without consulting the original version, where each expert back-translated a version that another expert translated. After this step, the experts evaluated the different English versions produced by comparing them with the original version of the questionnaire. It was verified the existence of semantics and content equivalence in most items - some items required adjusting to meet specific terminology and technical terms in Portuguese to ensure clarity and comprehensibility, achieved by discussion and consensus among the experts.

The same experts carried out the previous step of the content validity process. Each one was asked to express their opinion on the inclusion of the terms in the posed factors on a 10-point scale (disagreement/agreement) to calculate the Content Validity Index (CVI) [48]. The scores obtained revealed an agreement for all items with values above 80%, which indicates the suitability/inclusion of the items in their respective factors.

B. SAMPLE

Data collection counted with a sample of 603 subjects who completed the adapted version of the SSQ to the Portuguese language (348 males and 258 females) between 16 and 79 years old (M = 25.6, S.D. = 10.83). The sample was gathered from multiple studies that employed the same translated version of the questionnaire (more on subsection III-C)

The sample count was deemed high enough to robustly validate the questionnaire. Sources such as Fenn et al. [49] recommend a sample of 300 or at least 10 observations per item (we have 37.687 observations per item). For Comrey and Lee [50] the adequacy of sample size can be evaluated in the following manner: 50—very poor; 100—poor; 200—fair; 300—good; 500—very good; and 1000 excellent.

C. DATABASE

The database of this study comprises different data sources from 11 different immersive VR research studies that considered cybersickness as an dependent variable and adopted the Portuguese adaptation of the SSQ described in the previous section. These studies included different scenarios and research questions, providing an wide variety of situations where cybersickness can develop. The studies are listed below in Table 1.

D. STATISTICAL PROCEDURES

Using the AMOS (Analysis of Moment Structures) software in conjunction with SPSS (Statistical Package for the Social Sciences), we applied a methodology for quantitative data analysis capable of estimating the proposed theoretical model representing the relationships between the study's variables. The study's objective was adapting and validating the simulator sickness questionnaire for the Portuguese population. This validation was achieved through the utilization and estimation of a structural equation model, which allowed us to estimate the convergent validity between the study's variables. The fit of the estimated model was assessed using the Comparative Fit Index (CFI).

In order to ascertain the available sample, a descriptive analysis of the data was done using IBM SPSS 27 software. The internal consistency and reliability of the SSQ items and factors [60], [61] adapted for the Portuguese population (resulting in the SSQp) were also checked through the Cronbach's Alpha and its respective exploratory factor analysis (EFA). EFA was used to simplify the set of data that were obtained, assessing how much each factor is associated with each variable and examining how all the factors account for the various results obtained in the sample through the sum of the variance of the original variables [62]. After EFA had been done to determine the scale's multifactor nature and how items are spontaneously grouped, the CFA was conducted using the Amos 27 software.

The CFA includes a set of techniques that measure the dimensions of a scale [63], allowing one to test a hypothesis regarding several factors assessing the reliability of the scale's indicators [64]. A minimum of five questionnaires per item is often recommended for factor analysis [65]. According to the CFA, if an item has a high load, it indicates the factor and the item it corresponds to have much in common; loads under 0.32 are considered to be very weak, between 0.32 and 0.45 weak, between 0.45 and 0.63 good and over 0.71 very good [66].

IV. RESULTS

A. EXPLORATORY FACTOR ANALYSIS (EFA)

In Portugal, studies on the Simulator Sickness Questionnaire (SSQ) structural model were not found; therefore, the original version of the scale, the SSQ, was adapted, resulting in the SSQp, which was applied to Portuguese citizens. Thus, an Exploratory Factor Analysis was then conducted to verify whether the factor model of SSQp was in keeping with the literature. Factors and their respective oblique rotation were extracted by means of the Main Components Method (MCP) and only values whose factors were ≥ 1 were considered. Results included a Kaiser-Meyer-Olkin (KMO)=0.866 and a four-factor correlation matrix, which account for 57.08%

TABLE 1. **Identification of the studies used for generating the database.**

Study Title	Sample
Presence and cybersickness in immersive content: Effects of content type, exposure time and gender [24]	128
A Comparative Study Between Wired and Wireless Virtual Reality Setups [34]	117
The Relationship Between Cybersickness, Sense of Presence, and the Users [51]	90
A novel method to enhance the touristic 360 promotional video experience [52]	50
Delivering critical stimuli for decision making in VR training: Evaluation study of a firefighter training scenario [53]	48
The Impact of Olfactory and Wind Stimuli on 360 Videos Using Head-mounted Displays [54]	48
Evaluation of Animation and Lip-Sync of Avatars, and User Interaction in Immersive Virtual Reality Learning Environments [55]	48
Virtual reality for training-the impact of smell on presence, cybersickness, fatigue, stress and knowledge transfer [56]	24
Does gamification in virtual reality improve second language learning [57]	20
Multisensory virtual environment for firefighter training simulation [58]	20
Presence in Virtual Environments: Objective Metrics vs Subjective Metrics - A Pilot Study [59]	10
Total	603

TABLE 2. **Exploratory Factor Analysis of the SSQp sample regarding Portuguese citizens. NAU - Nausea; DISC - Oculomotor Discomfort; DISO - Disorientation; CYBER - Cybersickness.**

Constructs	Variables	Factors			
		1	2	3	4
NAU	SSQ1	0.673			
	SSQ8	0.536			
	SSQ9	0.573			
DISC	SSQ2		0.609		
	SSQ3		0.667		
	SSQ4		0.659		
DISO	SSQ5			0.575	
	SSQ10			0.632	
	SSQ11			0.658	
	SSQ12			0.755	
	SSQ13			0.521	
	SSQ14			0.561	
CYBER	SSQ6				0.494
	SSQ7				0.394
	SSQ15				0.559
	SSQ16				0.340

of the variance. Other extractions with a higher number of factors were simulated, maintaining the same extraction criterion: ≥ 1. However, factor distribution and variance percentage values were in keeping with other studies. This way, using four factors, it was possible to verify that the exploratory factor model produced a best structural model. Table 2 presents the exploratory factor matrix regarding all adapted items of SSQp and their respective factor load, showing how variables are distributed into the four EFA ensuing factors. These items were divided within the four original constructs of SSQ: NAU - Nausea; DISC - Oculomotor Discomfort; DISO - Disorientation; CYBER - Cybersickness.

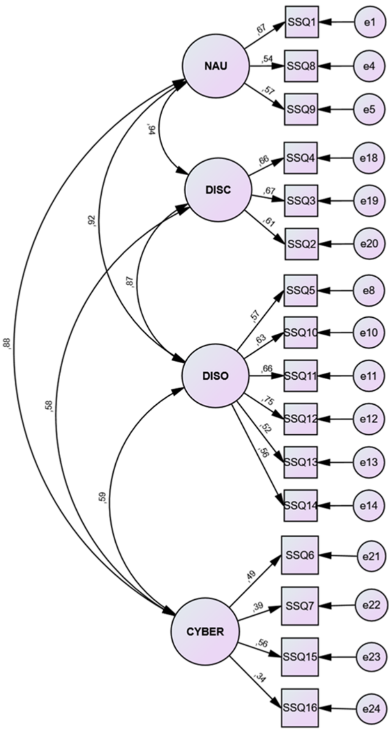

FIGURE 1. **SSQp final measurement model.**

B. CONFIRMATORY FACTOR ANALYSIS (CFA)

Regarding Confirmatory Factor Analysis, choosing the best factor model is essential, provided factor loads and errors that have been observed statistically validate it and prove its suitability for the study in question [64], [65], [67].

To perform the CFA, the final model was tested, including all items of the scale. Concerning factor loading, we obtain all factors with loadings higher than 0.3. Because of that, we cannot remove any scale variable to have a very good model adjustment with statistical robustness. Cronbach's Alpha is a statistical measure used to assess the internal reliability of a questionnaire or scale.

In general terms, a Cronbach's Alpha value above 0.7 is considered reasonably reliable for research studies. Values above 0.8 are considered good, and values above 0.9 are considered excellent.

A good total internal consistency was observed ($\alpha = 0.858$) for the sample composed of 603 Portuguese citizens. Given the 4-factor structural model that was adopted, the internal consistency of the items was as follows: NAU ($\alpha = 0.707$); DISC ($\alpha = 0.771$); DISO ($\alpha = 0.767$) and CYBER ($\alpha = 0.727$).

In terms of the final measurement model, Figure 1 presents the standard path coefficients, showing that they were all significant ($p < 0.001$).

V. DISCUSSION

Cybersickness is crucial when experiencing virtual experiences that could compromise other data if participants feel unwell. The SSQ is one of the most used questionnaires to address the severity of cybersickness symptoms in immersive VR. Thus, translating and validating this instrument to other languages is highly important. There is a lack of validated instruments to address cybersickness in the Portuguese language. Thus, the present study proposed the validation of the SSQ for the Portuguese sample, called SSQp, through a sample of 603 subjects from Portugal.

The questionnaire was subjected to validation procedures for the Portuguese sample. This involved employing tailored techniques such as semantic and content analysis of the items, resulting in enhanced construct validity and internal consistency. CFA was applied to maintain the original structure of the theoretical model. This ensured that the same number of factors and items were retained, aligning with the validation theory's assumptions [68].

In our investigation of the SSQp's validity and structural properties, we employed Exploratory Factor Analysis (EFA), a statistical technique designed to delve into the latent factor structure within a dataset. EFA, using the Main Components Method (MCP) for factor extraction, was utilized as it is a widely accepted approach for uncovering the underlying factors in the dataset. The outcomes of the EFA revealed a KMO value of 0.866, indicating the appropriateness of the dataset for factor analysis. Furthermore, a four-factor correlation matrix was identified, which explains 57.08% of the variance. This observation implies that the four factors identified during the analysis play a substantial role in capturing variations within the data. Furthermore, the alignment of factor distribution and variance percentage values with findings from analogous studies underscores the consistency of our results with existing research on similar topics. Therefore, we can conclude that the four-factor structure provides the most suitable representation of the questionnaire's underlying dimensions in the context of the Portuguese population. Confirmatory Factor Analysis (CFA) was subsequently employed, given the support for its appropriateness in our research context, as suggested by existing literature. The CFA was performed based on a final model that included all scale items, emphasizing factor loadings, which signify the strength of the relationship between observed variables (items) and their latent factors. To evaluate internal consistency, we introduced Cronbach's Alpha as a metric. This measure assesses whether the questionnaire items consistently gauge the same underlying construct. Notably, the Cronbach's Alpha value for our sample of 603 Portuguese citizens was calculated at 0.858, indicating a commendable level of internal consistency for the entire scale. Moreover, our examination of internal consistency across the four distinct factors (NAU, DISC, DISO, and CYBER) revealed consistently high values, reinforcing the robustness of these dimensions within the scale. Additionally, the observation of all path coefficients being statistically significant underscores the meaningfulness of the relationships in our measurement model.

VI. CONCLUSION

In conclusion, our study focused on adapting and validating the SSQp (Portuguese Simulator Sickness Questionnaire) for use among Portuguese citizens. We conducted both Exploratory Factor Analysis (EFA) and Confirmatory Factor Analysis (CFA) to assess the validity and structural properties of the questionnaire. The EFA revealed that a four-factor structure is the most suitable representation of the SSQp's underlying dimensions in Portuguese. This model was well-aligned with the literature and explained a substantial portion of the variance in the data. It suggests that the adapted questionnaire effectively captures the relevant aspects of SSQ in the Portuguese population. Subsequently, the CFA results further confirmed the robustness of the measurement model. Factor loadings, path coefficients, and the overall Cronbach's Alpha value (0.858) indicated high internal reliability and consistency. The individual factors, including NAU, DISC, DISO, and CYBER, also displayed commendable internal consistency. These findings underscore the appropriateness of the SSQp as a tool for assessing simulator sickness in the Portuguese context. The questionnaire demonstrates strong psychometric properties and can be reliably used in research and practical applications to evaluate and, therefore, take the appropriate measures to mitigate simulator-related discomfort or adverse experiences.

There are some limitations when using the SSQp questionnaire. The sample used to validate the questionnaire was from Portugal and utilized European Portuguese. Consequently, minor cultural differences may affect how items are interpreted in other variations of Portuguese, such as Brazilian Portuguese. Therefore, it is important to test the questionnaire's validity with different varieties of Portuguese. Despite this, the SSQp questionnaire is still more appropriate than the original English version for these demographics. Alternatively, researchers can make the necessary adjustments to adapt the SSQp European Portuguese version to other Portuguese variations. Even though the SSQp was validated using cybersickness data from multiple studies, all subjects were exposed to immersive VR, a subset of experiences that can cause cybersickness. Thus, further studies are needed to confirm the validity of the questionnaire for other types of setups.

VII. CONFLICT OF INTEREST STATEMENT

None of the authors have a conflict of interest to disclose.

REFERENCES

[1] M. Slater, "Immersion and the illusion of presence in virtual reality," *Brit. J. Psychol.*, vol. 109, no. 3, pp. 431–433, Aug. 2018.

[2] G. Gonçalves, H. Coelho, P. Monteiro, M. Melo, and M. Bessa, "Systematic review of comparative studies of the impact of realism in immersive virtual experiences," *ACM Comput. Surv.*, vol. 55, no. 6, pp. 1–36, Jul. 2023.

[3] M. Slater and S. Wilbur, "A framework for immersive virtual environments (FIVE): Speculations on the role of presence in virtual environments," *Presence, Teleoperators Virtual Environ.*, vol. 6, no. 6, pp. 603–616, Dec. 1997.

[4] M. Melo, G. Gonçalves, P. Monteiro, H. Coelho, J. Vasconcelos-Raposo, and M. Bessa, "Do multisensory stimuli benefit the virtual reality experience? A systematic review," *IEEE Trans. Vis. Comput. Graphics*, vol. 28, no. 2, pp. 1428–1442, Feb. 2022.

[5] J. J. LaViola, "A discussion of cybersickness in virtual environments," *ACM SIGCHI Bull.*, vol. 32, no. 1, pp. 47–56, Jan. 2000, doi: 10.1145/333329.333344.

[6] A. N. R. Chandra, F. El Jamiy, and H. Reza, "A systematic survey on cybersickness in virtual environments," *Computers*, vol. 11, no. 4, p. 51, Mar. 2022.

[7] S. Weech, S. Kenny, and M. Barnett-Cowan, "Presence and cybersickness in virtual reality are negatively related: A review," *Frontiers Psychol.*, vol. 10, p. 158, Feb. 2019.

[8] J. M. Mittelstaedt, J. Wacker, and D. Stelling, "VR aftereffect and the relation of cybersickness and cognitive performance," *Virtual Reality*, vol. 23, no. 2, pp. 143–154, Jun. 2019.

[9] K. Nesbitt, S. Davis, K. Blackmore, and E. Nalivaiko, "Correlating reaction time and nausea measures with traditional measures of cybersickness," *Displays*, vol. 48, pp. 1–8, Jul. 2017.

[10] S. Davis, K. Nesbitt, and E. Nalivaiko, "A systematic review of cybersickness," in *Proc. Conf. Interact. Entertainment*, Dec. 2014, pp. 1–9.

[11] J. T. Reason and J. J. Brand, *Motion Sickness*. New York, NY, USA: Academic, 1975.

[12] M. Treisman, "Motion sickness: An evolutionary hypothesis," *Science*, vol. 197, no. 4302, pp. 493–495, Jul. 1977.

[13] G. E. Riccio and T. A. Stoffregen, "An ecological theory of motion sickness and postural instability," *Ecolog. Psychol.*, vol. 3, no. 3, pp. 195–240, Sep. 1991.

[14] L. Alcock, T. D. O'Brien, and N. Vanicek, "Association between somatosensory, visual and vestibular contributions to postural control, reactive balance capacity and healthy ageing in older women," *Health Care Women Int.*, vol. 39, no. 12, pp. 1366–1380, Dec. 2018.

[15] Y. Ivanenko and V. S. Gurfinkel, "Human postural control," *Frontiers Neurosci.*, vol. 12, p. 171, Mar. 2018.

[16] E. M. Kolasinski, "Simulator sickness in virtual environments," Army Res. Inst. Behav. Social Sci., Alexandria, VA, USA, Tech. Rep. 1027, 1995.

[17] K. Petri, K. Feuerstein, S. Folster, F. Bariszlovich, and K. Witte, "Effects of age, gender, familiarity with the content, and exposure time on cybersickness in immersive head-mounted display based virtual reality," *Amer. J. Biomed. Sci.*, vol. 12, no. 2, pp. 107–121, Apr. 2020.

[18] D. M. Shafer, C. P. Carbonara, and M. F. Korpi, "Modern virtual reality technology: Cybersickness, sense of presence, and gender," *Media Psychol. Rev.*, vol. 11, no. 2, p. 1, 2017.

[19] F. Biocca, "Will simulation sickness slow down the diffusion of virtual environment technology?" *Presence, Teleoperators Virtual Environ.*, vol. 1, no. 3, pp. 334–343, Jan. 1992.

[20] K. Stanney, C. Fidopiastis, and L. Foster, "Virtual reality is sexist: But it does not have to be," *Frontiers Robot. AI*, vol. 7, p. 4, Jan. 2020.

[21] M. E. McCauley and T. J. Sharkey, "Cybersickness: Perception of self-motion in virtual environments," *Presence, Teleoperators Virtual Environ.*, vol. 1, no. 3, pp. 311–318, Jan. 1992.

[22] K. M. Stanney, K. S. Hale, I. Nahmens, and R. S. Kennedy, "What to expect from immersive virtual environment exposure: Influences of gender, body mass index, and past experience," *Hum. Factors, J. Hum. Factors Ergonom. Soc.*, vol. 45, no. 3, pp. 504–520, Sep. 2003.

[23] L. Rebenitsch and C. Owen, "Estimating cybersickness from virtual reality applications," *Virtual Reality*, vol. 25, no. 1, pp. 165–174, Mar. 2021.

[24] M. Melo, J. Vasconcelos-Raposo, and M. Bessa, "Presence and cybersickness in immersive content: Effects of content type, exposure time and gender," *Comput. Graph.*, vol. 71, pp. 159–165, Apr. 2018.

[25] D. Risi and S. Palmisano, "Effects of postural stability, active control, exposure duration and repeated exposures on HMD induced cybersickness," *Displays*, vol. 60, pp. 9–17, Dec. 2019.

[26] S. Sharples, S. Cobb, A. Moody, and J. R. Wilson, "Virtual reality induced symptoms and effects (VRISE): Comparison of head mounted display (HMD), desktop and projection display systems," *Displays*, vol. 29, no. 2, pp. 58–69, Mar. 2008.

[27] M. Melo, G. Gonçalves, D. Narciso, and M. Bessa, "Impact of different role types and gender on presence and cybersickness in immersive virtual reality setups," in *Proc. Int. Conf. Graph. Interact. (ICGI)*, Nov. 2021, pp. 1–8.

[28] S. Palmisano, R. Mursic, and J. Kim, "Vection and cybersickness generated by head-and-display motion in the oculus rift," *Displays*, vol. 46, pp. 1–8, Jan. 2017.

[29] T. M. Porcino, E. Clua, D. Trevisan, C. N. Vasconcelos, and L. Valente, "Minimizing cyber sickness in head mounted display systems: Design guidelines and applications," in *Proc. IEEE 5th Int. Conf. Serious Games Appl. Health (SeGAH)*, Apr. 2017, pp. 1–6.

[30] J.-P. Stauffert, F. Niebling, and M. E. Latoschik, "Latency and cybersickness: Impact, causes, and measures. A review," *Frontiers Virtual Reality*, vol. 1, Nov. 2020, Art. no. 582204.

[31] J. Davis, Y.-H. Hsieh, and H.-C. Lee, "Humans perceive flicker artifacts at 500 Hz," *Sci. Rep.*, vol. 5, no. 1, p. 7861, Feb. 2015.

[32] N. Waldin, M. Waldner, and I. Viola, "Flicker observer effect: Guiding attention through high frequency flicker in images," *Comput. Graph. Forum*, vol. 36, no. 2, pp. 467–476, May 2017.

[33] S. Vlahovic, M. Suznjevic, N. Pavlin-Bernardic, and L. Skorin-Kapov, "The effect of VR gaming on discomfort, cybersickness, and reaction time," in *Proc. 13th Int. Conf. Quality Multimedia Exper. (QoMEX)*, Jun. 2021, pp. 163–168.

[34] G. Gonçalves, P. Monteiro, M. Melo, J. Vasconcelos-Raposo, and M. Bessa, "A comparative study between wired and wireless virtual reality setups," *IEEE Access*, vol. 8, pp. 29249–29258, 2020.

[35] G. Gonçalves, P. Monteiro, H. Coelho, M. Melo, and M. Bessa, "Systematic review on realism research methodologies on immersive virtual, augmented and mixed realities," *IEEE Access*, vol. 9, pp. 89150–89161, 2021.

[36] B. Peixoto, L. C. P. Bessa, G. Gonçalves, M. Bessa, and M. Melo, "Teaching EFL with immersive virtual reality technologies: A comparison with the conventional listening method," *IEEE Access*, vol. 11, pp. 21498–21507, 2023.

[37] D. Narciso, M. Melo, S. Rodrigues, J. P. Cunha, J. Vasconcelos-Raposo, and M. Bessa, "Studying the influence of multisensory stimuli on a firefighting training virtual environment," *IEEE Trans. Vis. Comput. Graphics*, early access, Mar. 2, 2023, doi: 10.1109/TVCG.2023.3251188.

[38] E. Nalivaiko, S. L. Davis, K. L. Blackmore, and K. V. Nesbitt, "Cybersickness provoked by head-mounted display affects cutaneous vascular tone, heart rate and reaction time," *Autonomic Neurosci.*, vol. 192, p. 63, Nov. 2015.

[39] S. H. Yip and J. Saunders, "Restricting the distribution of visual attention reduces cybersickness," *J. Vis.*, vol. 23, no. 9, p. 4784, Aug. 2023.

[40] A. Prithul, I. B. Adhanom, and E. Folmer, "Teleportation in virtual reality; a mini-review," *Frontiers Virtual Reality*, vol. 2, p. 138, Oct. 2021.

[41] R. S. Kennedy, N. E. Lane, K. S. Berbaum, and M. G. Lilienthal, "Simulator sickness questionnaire: An enhanced method for quantifying simulator sickness," *Int. J. Aviation Psychol.*, vol. 3, no. 3, pp. 203–220, Jul. 1993.

[42] P. J. Gianaros, E. R. Muth, J. T. Mordkoff, M. E. Levine, and R. M. Stern, "A questionnaire for the assessment of the multiple dimensions of motion sickness," *Aviation, Space, Environ. Med.*, vol. 72, no. 2, p. 115, 2001.

[43] B. Keshavarz and H. Hecht, "Validating an efficient method to quantify motion sickness," *Hum. Factors, J. Hum. Factors Ergonom. Soc.*, vol. 53, no. 4, pp. 415–426, Aug. 2011.

[44] H. K. Kim, J. Park, Y. Choi, and M. Choe, "Virtual reality sickness questionnaire (VRSQ): Motion sickness measurement index in a virtual reality environment," *Appl. Ergonom.*, vol. 69, pp. 66–73, May 2018.

[45] R. S. Kellogg, R. S. Kennedy, and A. Graybiel, *Motion Sickness Symptomatology Labyrinthine Defective Normal Subjects During Zero Gravity Maneuvers*. Wright-Patterson AFB, OH, USA: Aerospace Medical Research Laboratories, 1964.

[46] R. W. Brislin, "Back-translation for cross-cultural research," *J. Cross-Cultural Psychol.*, vol. 1, no. 3, pp. 185–216, Sep. 1970.

[47] R. K. Hambleton and A. L. Zenisky, "Translating and adapting tests for cross-cultural assessments," in *Cross-Cultural Research Methods in Psychology*, D. Matsumoto and F. J. R. van de Vijver, Eds., Cambridge, U.K.: Cambridge Univ. Press, 2010, pp. 46–70. [Online]. Available: https://www.cambridge.org/core/books/abs/crosscultural-research-methods-in-psychology/translating-and-adapting-tests-for-crosscultural-assessments/EA98D8AD9AFB9AEDC872531BA1A9BB06

[48] E. R. Lenz, *Measurement in Nursing and Health Research*. Cham, Switzerland: Springer, 2010.

[49] J. Fenn, C.-S. Tan, and S. George, "Development, validation and translation of psychological tests," *BJPsych Adv.*, vol. 26, no. 5, pp. 306–315, Sep. 2020.

[50] A. L. Comrey and H. B. Lee, *A First Course in Factor Analysis*. London, U.K.: Psychology Press, 2013.

[51] M. Magalhães, M. Melo, M. Bessa, and A. F. Coelho, "The relationship between cybersickness, sense of presence, and the users' expectancy and perceived similarity between virtual and real places," *IEEE Access*, vol. 9, pp. 79685–79694, 2021.

[52] G. Gonçalves, M. Melo, J. Vasconcelos-Raposo, and M. Bessa, "A novel method to enhance the touristic 360 promotional video experience," *Multimedia Tools Appl.*, vol. 79, nos. 31–32, pp. 22905–22927, Aug. 2020.

[53] P. Monteiro, M. Melo, A. Valente, J. Vasconcelos-Raposo, and M. Bessa, "Delivering critical stimuli for decision making in VR training: Evaluation study of a firefighter training scenario," *IEEE Trans. Human-Mach. Syst.*, vol. 51, no. 2, pp. 65–74, Apr. 2021.

[54] D. Narciso, M. Melo, J. Vasconcelos-Raposo, and M. Bessa, "The impact of olfactory and wind stimuli on 360 videos using head-mounted displays," *ACM Trans. Appl. Perception*, vol. 17, no. 1, pp. 1–13, Jan. 2020.

[55] B. Peixoto, M. Melo, L. Cabral, and M. Bessa, "Evaluation of animation and lip-sync of avatars, and user interaction in immersive virtual reality learning environments," in *Proc. Int. Conf. Graph. Interact. (ICGI)*, Nov. 2021, pp. 1–7.

[56] D. Narciso, M. Bessa, M. Melo, and J. Vasconcelos-Raposo, "Virtual reality for training—The impact of smell on presence, cybersickness, fatigue, stress and knowledge transfer," in *Proc. Int. Conf. Graph. Interact. (ICGI)*, Nov. 2019, pp. 115–121.

[57] R. D. Pinto, P. Monteiro, M. Melo, L. Cabral, and M. Bessa, "Does gamification in virtual reality improve second language learning?" in *Proc. Int. Conf. Graph. Interact. (ICGI)*, Nov. 2021, pp. 1–8.

[58] L. Barbosa, P. Monteiro, M. Pinto, H. Coelho, M. Melo, and M. Bessa, "Multisensory virtual environment for firefighter training simulation: Study of the impact of haptic feedback on task execution," in *Proc. 24° Encontro Português de Computação Gráfica e Interação (EPCGI)*, Oct. 2017, pp. 1–7.

[59] M. Melo, T. Rocha, L. Barbosa, and M. Bessa, "Presence in virtual environments: Objective metrics vs. subjective metrics—A pilot study," in *Proc. 23rd Portuguese Meeting Comput. Graph. Interact. (EPCGI)*, Nov. 2016, pp. 1–6.

[60] J. F. Hair Jr., M. Sarstedt, L. Hopkins, and V. G. Kuppelwieser, "Partial least squares structural equation modeling (PLS-SEM): An emerging tool in business research," *Eur. Bus. Rev.*, vol. 26, no. 2, pp. 106–121, Mar. 2014.

[61] B. M. Byrne, *Structural Equation Modeling With Mplus: Basic Concepts, Applications, and Programming*. Evanston, IL, USA: Routledge, 2013.

[62] D. L. Jackson, J. A. Gillaspy, and R. Purc-Stephenson, "Reporting practices in confirmatory factor analysis: An overview and some recommendations," *Psychol. Methods*, vol. 14, no. 1, pp. 6–23, Mar. 2009.

[63] R. G. Netemeyer, W. O. Bearden, and S. Sharma, *Scaling Procedures: Issues and Applications*. Newbury Park, CA, USA: Sage, 2003.

[64] T. A. Brown, *Confirmatory Factor Analysis for Applied Research*. New York, NY, USA: Guilford Publications, 2015.

[65] J. F. Hair, W. C. Black, B. J. Babin, and R. E. Anderson, *Multivariate Data Analysis*. Prentice-Hall, 2009.

[66] R. B. Kline, *Principles and Practice of Structural Equation Modeling*. New York, NY, USA: Guilford Publications, 2023.

[67] B. Thompson, *Exploratory and Confirmatory Factor Analysis: Understanding Concepts and Applications*, vol. 10694. Washington, DC, USA: Citeseer, 2004, p. 3.

[68] F. M. Cheung, F. J. R. van de Vijver, and F. T. L. Leong, "Toward a new approach to the study of personality in culture," *Amer. Psycholog.*, vol. 66, no. 7, pp. 593–603, Oct. 2011.

GUILHERME GONÇALVES received the bachelor's degree from University of Trás-os-Montes e Alto Douro (UTAD), Portugal, in 2015, where he is currently pursuing the M.Sc. degree in multimedia. Since 2018, he has been a Research Fellow with INESC TEC, Porto, Portugal. He is a Invited Professor at the University of Trás-os-Montes e Alto Douro. His main research interest includes multisensory virtual reality.

MIGUEL MELO is currently an Assistant Professor with the Department of Engineering, University of Trás-os-Montes e Alto Douro, Portugal, and a Senior Researcher with INESC TEC. He is the Research and Development Manager of the MASSIVE Virtual Reality Laboratory. He participated in several national and international projects in the field of virtual reality and has published more than 90 scientific papers in internationally indexed journals and conferences. His research interests include computer graphics, HDR, and multisensory virtual reality. He is a member of the Eurographics Executive Committee.

CARLOS SERÔDIO is currently an Associate Professor (with Habilitation) with the Engineering Department, School of Sciences and Technology, UTAD, Portugal. He is a member of the Embedded Systems Research Line of ALGORITMI (University of Minho). He was a colaborator with the Biosystems Engineering Group of CITAB (UTAD) until 2023. He has supervised 60 M.Sc. thesis and five Ph.D. thesis and has two patents. His research interests include wireless sensors networks, precision agriculture, smart cities, and indoor localization using wireless networks. He has participated in several international conferences as a presenter and the chair of sessions as well member of the Program Committee, the Technical Committee, and the Scientific Committee, and a reviewer. He has also been a reviewer of international journals and international conferences.

RUI SILVA received the Ph.D. degree in management from the University of Beira Interior, Covilhã, Portugal. He is currently an Assistant Professor with University of Trás-os-Montes e Alto Douro (UTAD), belonging to the Department of Economics, Sociology and Management (DESG) of the School of Human and Social Sciences (ECHS) where, he teaches several curricular units in the courses of the bachelor's degree in management, economics and tourism, the master's degree in management, and the Ph.D. degree in development, societies and territories. He is the Director of the Master of Management and the President of the Commission for Gender Equality, UTAD. He is a Senior Researcher with the Centre for Transdisciplinary Development Studies (CETRAD), with publications in several scientific journals indexed to the Web of Science and Scopus. The Curricular Units, he teaches are Financial Accounting I and II, Management Accounting, Management Control, Data Analysis, and Investment Projects. He also reviews several scientific journals and actively participates in international projects and conferences.

MAXIMINO BESSA is currently an Associate Professor with Habilitation at the Department of Engineering, University of Trás-os-Montes e Alto Douro, Portugal. He has been a Senior Researcher with INESC TEC since 2009 and the Director of the Multisensory Virtual Reality Laboratory MASSIVE. He has been a member of the Eurographics Association since 2003 and was President of the Portuguese Computer Graphics Chapter (2020–2022).