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# Identifying presence of cybersickness symptoms using AI-based predictive learning algorithms

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**Abstract**

Cybersickness (CS) affects a large proportion of virtual reality (VR) users causing a combination of nausea, headaches and dizziness which would create barriers to the users, VR designers/developers and the stakeholders in the production industry. Although design principles suggest methods to avoid CS, challenges remain as new demands and systems continue to penetrate the competitive market. The dilemma is whether to use VR technology by experiencing the ultimate virtual world using a head-mounted display (HMD) with possible CS triggers or to avoid the triggers by avoiding using VR. With the huge success and potential in the entertainment industry, it is very important to focus on the solutions to handling CS dilemmas. Therefore, the main observation for the developers is to have a guide around the set of established design principles aiming to broadly reduce CS. In this paper, we provide a method to apply artificial intelligence (AI) techniques and use machine learning (ML) algorithms including support vector machines (SVMs), decision trees (DTs) and K-nearest neighbours (KNNs) to predict CS outcomes. Based on our findings, we have observed that DT and SVM surpassed KNN in test accuracy. Additionally, DT exhibited better results than both SVM and KNN in train accuracy. By exploiting the power of ML, developers will be able to predict the potential occurrence of CS while developing VR projects to find ways to alleviate CS more effectively.

**Keywords** Cybersickness (CS) · Virtual reality (VR) · Head-mounted displays (HMDs) · Machine learning (ML) · Artificial intelligence (AI) · Support vector machines (SVMs) · Decision trees (DTs) · K-nearest neighbours (KNNs)

## 1 Introduction

Virtual reality (VR) is a fast-growing technology sector, that provides technology solutions for consumer engagement in simulated virtual environments. The current target markets include gaming, industry simulations for a product review or testing, education and wellness. It usually involves the user wearing a head-mounted display (HMD) that places the screen in front of the user's eyes. A virtual 3D environment becomes part of the user's immersive experience that includes sensory, cognitive and physical motion cues. VR as a concept has existed since the 1960s (Sutherland 1965) and has now seen expansion of the technology to mass markets with as the HTC Vive (www.vive.com) and the Oculus Rift (www.oculus.com).

Now, VR is widely available to the public, general usability is important for users to uptake through a positive user experience. A challenge to the individual user is the possibility of triggering a level of cybersickness (CS). Once experienced the outcome can be unpleasant, and prevent the re-use of the product. The CS situation can be similar to motion sickness which occurs when the three sensory systems including the ears (vestibular system, eyes (vision) and functional (motion) systems conflict in response to VR immersive experience. CS affects a large population, for example, a 1999 study demonstrated that 80% of participants experienced CS within the first ten minutes of VR exposure (Cobb et al. 1999). Recent research on CS in VR continues to build on previous findings, aiming to better

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understand the causes and effects of this common issue and develop effective strategies for mitigating its impact. However, despite all the efforts, CS remains a significant obstacle to the widespread use of virtual reality due to discomfort and loss of immersion including balance, limited consideration of user susceptibility and visual focus (Tian et al. 2022; Caserman et al. 2021; Porcino et al. 2020). Adding to the recent achievement in the CS domain, predicting the occurrence of CS before exposure to 3D simulations would assist in addressing the complications.

Recently, a few studies on machine learning (ML)-based assessment tools are conducted to identify the cause of CS, heart rate effects, postural imbalance and vestibular dysfunction while immersion in the VR environment (Oh and Kim 2021; Jin et al. 2018; Yeh et al. 2014; Hadadi et al. 2022). It facilitates altering the design strategies where alleviating CS is the key. In this paper, we have applied ML algorithms to predict cybersickness among people who could be potential users of VR. Due to its compatibility, adaptability and applicability in various fields, VR has the potential to serve a wide range of users, including older adults, people with conditions such as dementia and those experiencing non-virtuous dizziness (Pastel et al. 2022; Díaz Pérez and Flórez Lozano 2018; Zaidi et al. 2022). The results show that the approach could be applied to predict CS effectively for potential users who have not experienced VR immersion. This approach will possibly assist the health sector to understand ways to develop VR-based interventions for people with persistent postural-perceptual dizziness symptoms.

## 2 Background

The phenomenon of cybersickness (CS), symptoms of nausea, dizziness and disorientation, is not new when it comes to exposure to virtual reality. CS is triggered when the user is caught in the mismatch between the visual and vestibular cue, where the eyes are experiencing movement, and the body is standing still in reality (Davis et al. 2014).

CS has been the focus of studies mainly addressing locomotion techniques, software quality and design techniques to identify the alleviation process of the symptoms. Data are extracted based on the techniques covering different cybersickness-causing factors and/or alleviation outcomes. It is important to work towards understanding and minimising CS for better accessibility of VR technology to a wider audience (Tian et al. 2022; Ramaseri Chandra et al. 2022). Studies found that locomotion has been identified as one of the main causes of CS, and the techniques to improve locomotion have been identified as keys to reducing the symptoms of cybersickness (Bishop and Abid 2018). Locomotion is where users are placed in large virtual worlds where they roam around the immersive environment through controls. As a result, it sends mixed signals to the brain, as the eyes see themselves moving through an environment, but the vestibular system does not feel any motion, resulting in a phenomenon called vection—the false impression of self-motion (Dichgans and Brandt 1978). In real life, passengers would experience more intensive sickness than drivers, as they are not in control of the predetermined path (Shafiabady et al. 2023). Similarly, one observation has reported that higher navigation speeds lead to increased severity of CS ratings (Kwok et al. 2018). A lower and unsteady frame rate can lead to jarring and inconsistent movements in the VR immersive experiences causing unwanted CS (Stauffert et al. 2018; Louis et al. 2019).

Since 2018, various effective methods have been proposed to closely monitor CS and to find a solution, for example, steering locomotions, teleporting and adding modality to detect the level of CS locomotion based on the presence and hybrid locomotion (Mayor et al. 2019; Clifton and Palmisano 2020; Yamamura et al. 2020; Paroz and Potter 2018). Also, recent research showed that improved versions of locomotion techniques like gaze-directed steering, pointing-directed steering and teleporting can keep the user comfortable and engaging in VR by alleviating any symptoms of VR-based dizziness (Christou and Aristidou 2017; Zielasko et al. 2020; Prithul et al. 2021; Donabauer 2019). Moreover, teleporting has resulted in hasting to complete the task and getting out of the VR environment. Another study has reported teleportation to be the locomotion technique that resulted in the lowest level of CS among participants (Boletsis and Chasanidou 2022). Researchers have observed that having a predetermined path of movement resulted in lower levels of sickness for the users (Boletsis and Chasanidou 2022). A lower and unsteady frame rate can lead to jarring and inconsistent movements in the VR immersive experiences causing unwanted CS (Stauffert et al. 2018; Louis et al. 2019). Several software techniques have been employed to alleviate cybersickness in VR, such as dynamically adjusting the user's field of view (Choroś and Nippe 2019), distorting geometry (Lou and Chardonnet 2019) and inducing temporary vision blurring during rotation (Budhiraja et al. 2017). Moreover, a study proposes a method to mitigate cybersickness symptoms that involves extrapolating users' head movements to predict their future movements (Garcia-Agundez et al. 2017). Quality concerns are another factor often thought to be a cause of CS (Choroś and Nippe 2019). Image quality, the resolution of the image displayed on the screens of the HMD, is a factor affecting CS (Choroś and Nippe 2019). Studies have shown that maintaining the magnitude and steadiness of high frame rate support users engaged in the VR environment without any mismatch of visual and vestibular cues that causes CS (Louis et al. 2019). Moreover, studies have reported that a difference in CS ratings was observed between different VR devices (Kwok et al. 2018; Agić et al. 2020). Designing an appropriate VR experience to maintain user engagement and interactivity is important for the wider acceptability of the technology. Longer session lengths in VR have been shown to cause CS more often for users (Choroś and Nippe 2019; Zaidi and Male 2018). Studies have shown that including game-like elements and manipulating scenes as per user requirements can help increase engagement and mitigate the occurrence of CS (Shin 2019; Pallavicini and Pepe 2020). Therefore, it is important for the developers to either do to keep the users in exposure for a long time if the engagement is not variable or interactive through dynamic cues or keep the designed environment pleasing, relaxing and with minimal complexity in dynamism (Zielasko and Riecke 2021).

One study has used a combination of methods to record levels of CS, using the Simulator Sickness Questionnaire (SSQ) between each trial and recording MISC every minute during the trials. Monocular viewing using HMDs is associated with less likelihood of CS as compared to binocular viewing (Palmisano et al. 2019). SSQ is a type of survey questionnaire that employs a rating scale from 0 to 3, where 0 corresponds to no symptoms, 1 indicates slight symptoms, 2 denotes moderate symptoms, and 3 represents severe symptoms. The SSQ evaluates four areas to retrieve scores which include nausea, oculomotor and disorientation, to assess symptoms for specific aspects. The total score shows the overall severity of simulator sickness experienced by users of virtual reality systems (Kennedy et al. 1993; Sevinc and Berkman 2020). The non-invasive sensory simulation could also be considered one of the solutions for CS reduction (Weech et al. 2020).

Artificial intelligence (AI) is a technological contemporary approach that can replicate human cognitive processes and behaviour, enabling them to gain knowledge, make well-informed choices and react to unexpected situations (Zhao and Gómez Fariñas 2023). AI applications in virtual reality in various sectors show improvements in engagement and interactivity (Geraci 2010; Gandedkar et al. 2021; Laukkanen et al. 2004; Ambagtsheer et al. 2020; Zaidi et al. 2020). Recently, researchers have found that AI is an effective tool in predicting CS symptoms as it allows for the analysis of large datasets and the identification of patterns that may be difficult for humans to detect. For example, ML algorithms are used on physiological parameters including respiratory signals, heart rates and electrocardiogram (ECG) to predict the onset of cybersickness in VR users (Oh and Kim 2021; Hadadi et al. 2022; Islam et al. 2020). These studies have investigated parameters of immersive VR game factors and physiological signals in response to VR experience and have found high accuracies in their results.

The purpose of this study is to explore the methods which would provide accurate predictions on the existence of CS among VR users. We have applied three nonlinear supervised classification algorithms, namely, support vector machines (SVMs), K-nearest neighbours (KNNs) and decision tree (DT). The applied ML algorithms are explained and their predictive performance has been compared with each other within the upcoming sections. This approach would give a further boost to understanding CS in VR development. By using ML algorithms, we have been able to make accurate predictions on the future symptoms and triggers of CS among VR users.

Also, we have applied AI algorithms to predict the occurrence of CS using SSQ scores. The outcome of this study will help the developers predict CS among potential users and enable them to redesign their design and develop a VR system with less CS exposure.

# 3 Methodology

## 3.1 Study design, participants and setting

We have implemented a data analysis strategy that predicts the existence of CS symptoms among VR users based on SSQ scores. The outcome of this study will help VR developers to identify potential CS among users of VR technology and align their design strategies accordingly to enhance the users' experience. Additionally, this approach helps the developers who work closely with healthcare professionals in dealing with persistent postural–perceptual dizziness symptoms, to identify ways for improving inventions strategies. Seventy-nine records of SSQs of the participants (including male and female) were included for prediction tests and training outcomes using the three algorithms while comparing their accuracies. The study is based on the secondary nature of data synthesis and analysis (Curry et al. 2019). In this study, the ML decision-making system has been designed and developed using Ai-Labs to predict CS existence using the dataset (Figure 1). This approach will help the developers to understand and identify the existence of CS among the users of technology.

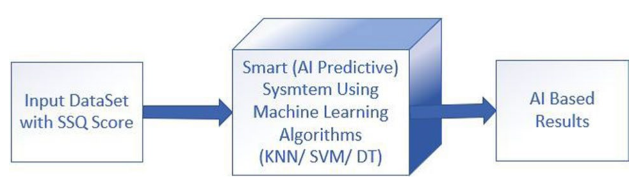


**Fig. 1** Smart (AI) systems for cybersickness

### 3.2 Data analysis using smart (machine learning) system

The data are divided to train and test sets; 85% of the data is used to train the system, and 15% is kept for testing the performance of the developed system on the unseen cases. The study has considered two sets of data. The first set is Group 1 (post-exposure SSQ scores <= 40), and the second set is Group 2 (post-exposure SSQ scores > 40). Having two groups based on young to mid-age and older people for predictive analysis is useful as it can provide an informed decision to the VR developers to specify the needs of each group (Group 1 and Group 2). For instance, the younger group could have different susceptibilities to cybersickness compared to older adults and may require different 3D immersive exposure. Additionally, designing VR applications for older adults could have particular benefits, such as improving cognitive function and quality of life (Zaidi et al. 2020, 2019; Pastel et al. 2022).

#### 3.2.1 Implementation of machine learning (ML) algorithms

In recent studies, different AI-based algorithms and methods have been applied for different purposes within the virtual reality domain to facilitate a better decision-making process (Zaidi et al. 2020; Li et al. 2020; Qi et al. 2021). In our case, three different ML algorithms have been used to identify hidden patterns and trends.

**3.2.1.1 Algorithm I-support vector machines (SVMs)** Support vector machine (SVM) is an ML classification algorithm with a good generalisation ability for the predictive process (Ambagtsheer et al. 2020; Widodo and Yang 2007; Shafiabady et al. 2023). The main features of SVM are fast optimisation capability in finding the solutions to classifications and regression problems. SVM has been applied on various scopes including pattern recognition and ranking function problems (Widodo and Yang 2007). SVM's capability in identifying the nonlinear patterns within the data and providing accurate prediction outcomes has encouraged researchers to apply this ML algorithm to solve different problems in a variety of domains including healthcare (Ambagtsheer et al. 2020).

**3.2.1.2 Algorithm III—decision tree (DT)** Based on the "divide and conquer" concept, this classification algorithm has been successful for predictive nonlinear regression analysis and classification (Yang 2010). As a supervised ML algorithm, decision trees split the data and analyse it according to certain parameters. Extensively used in data mining, decision-making with tree-like models facilitate rule-based decision-making and reaching a specific search goal (Ambagtsheer et al. 2020; Yang 2010; Navada et al. 2011).

**3.2.1.3 Algorithm II -K-nearest neighbours (KNNs)** KNN is developed to conduct discriminant analysis when it is difficult to determine/estimate the reliability of parameters of probability densities. Recently, this ML algorithm has been used for the predictive diagnosis of Parkinson's disease, fraud detection and decision information systems (Oh and Kim 2021; Shamrat et al. 2019; Malini and Pushpa 2017; Garcia-Agundez et al. 2019; Shirvan and Tahami 2011) and other areas. KNN has shown that it can accommodate data in different forms, for example video, audio and images (Batista and Silva 2009) and is easy to implement (Ambagtsheer et al. 2020).

#### 3.2.2 Predictive system

The AI has been trained on all of the participant records, using all three algorithms (KNN, DT and SVM). These proposed algorithms have been applied and compared with each other to predict post-exposure SSQ scores. Upon comparison of the results, the algorithm with better accuracy will be used to predict CS.

## 4 Results and discussion

The results of this experiment show that ML techniques could be of major assistance to developers in identifying the severity of potential CS symptoms with accuracy among the people who are prone to these symptoms. The performance of the abovementioned models has been compared with each other, and the results are depicted (Table 1).

**Table 1** Accuracy information of predictive applied ML algorithms

| ML algorithms | Prediction classification data | | | |
|---|---|---|---|---|
| | Test accuracy (%) | Train accuracy (%) | Test accuracy per group (%) | Train accuracy per group (%) |
| SVM | 93.34 | 82.81 | Group 1: 100 Group 2: 85.72 | Group 1: 88.24 Group 2: 76.67 |
| DT | 93.34 | 84.38 | Group 1: 100 Group 2: 85.72 | Group 1: 79.41 Group 2: 93.34 |
| KNN | 60 | 82.81 | Group 1: 100 Group 2: 14.72 | Group 1: 100.0 Group 2: 63.33 |

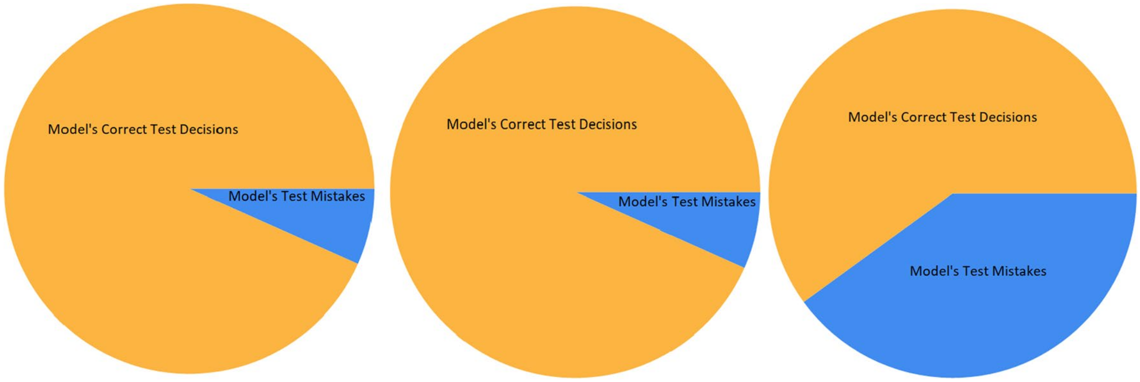


**Fig. 2** Test accuracy percentage: SVM (left), DT (mid) and KNN (right)

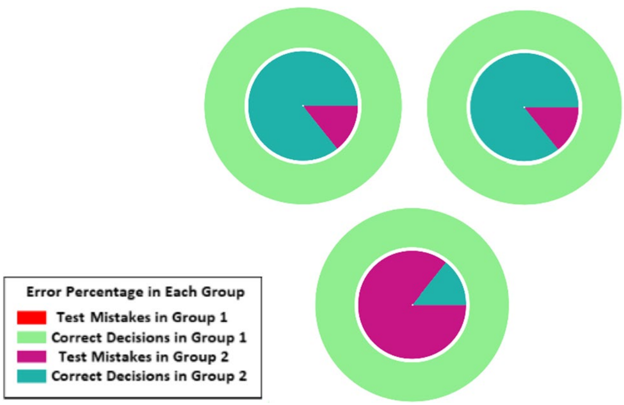


**Fig. 3** Train accuracy percentage: SVM (left), DT (mid) and KNN (right)

SVM achieved 93% test accuracy for the prediction of cybersickness for potential users of virtual reality technology using headsets. DT has matched the prediction accuracy of SVM with a test accuracy of 93% as well. This could be due to the nature and complexity of the data, and the training nature of KNN which has resulted in a lack of accurate predictive ability in identifying the complex existing hidden patterns. Figure 2 shows the test error percentages related to the three algorithms and Fig. 3 demonstrates their respective test error percentages. Furthermore, with all three algorithms, the test accuracies within each group have been compared with each other (as mentioned in section B above, Group 1 denotes post-exposure SSQ scores $< = 40$ and Group 2 represents post-exposure SSQ scores $> 40$). Figure 4 shows the test accuracies within each group and Fig. 5 demonstrates the same for the train set for the three algorithms. As is seen in the abovementioned figures and Table 1, SVM and DT have equally had 93.34% test accuracies. Comparing the train accuracies and the accuracies within each group (Table 1), DT has had a better train performance in comparison with the other algorithms since it has been able to create a more appropriate balance between the cases with and without CS considering the false-negative and false-positive results which are associated with specificity and sensitivity.

We suggest that developers should not only focus on test accuracy while selecting the algorithm. As in the figures, the results show that observation at the nearest match of actual output with the desired match is the key factor.

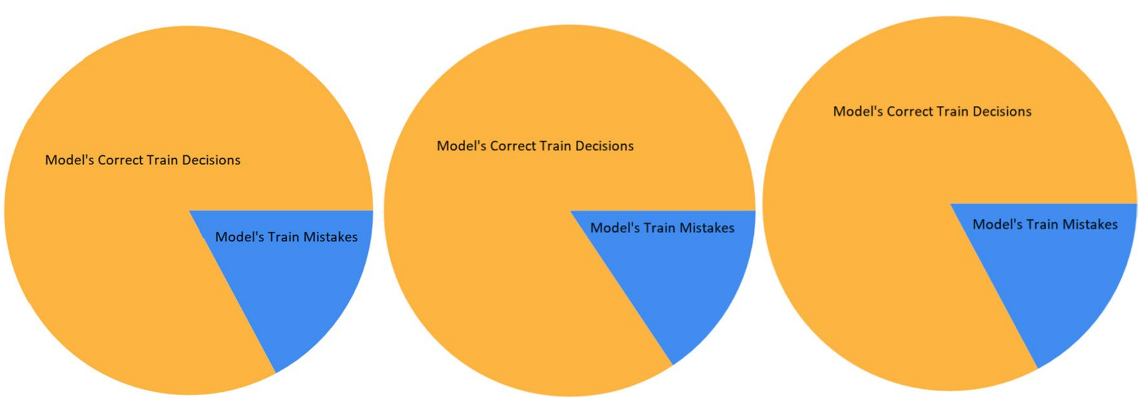


**Fig. 4** Test accuracy percentage for each group: SVM (top-left), DT (top-right) and KNN (bottom)

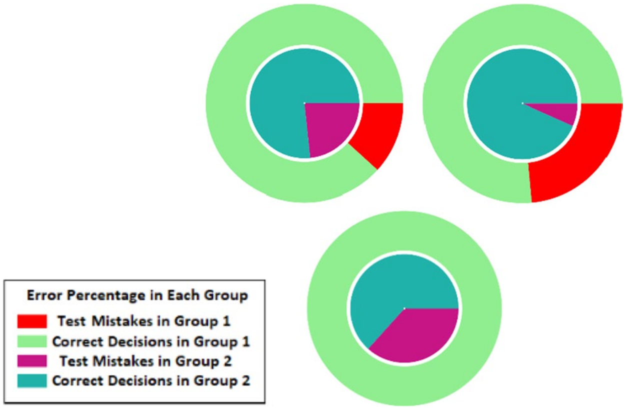


**Fig. 5** Train accuracy percentage for each group: SVM (top-left), DT (top-right) and KNN (bottom)

Apparently, with the accuracy prevailing the strengthen the core attributes of the algorithms, observation of matching outputs gets oblivious. It is to be noted that algorithms tend to produce false positives and negatives. By looking at the predictive results and true data, false positives are worth considering over false negatives. This comes with the fact that the developers will be able to consider how many users are comfortable with virtual reality technology in their daily entertainment life or for-purpose interventions from health science and/or education purpose.

The approach would allow developers to re-assess their ability, keenness and scope to generate more data information that could facilitate getting the desired accuracy where false positives and negatives could be controlled or reduced to a minimum.

To understand and predict CS, ML algorithms within their capacity are helpful to address and facilitate design methodologies that alleviate the sickness (Jin et al. 2018; Porcino et al. 2022). AI in its different forms is entering every other discipline to impact society in a meaningful way. The virtual reality world is no different where AI is paving the way in VR giving developers to look beyond the visual aspect of it (Beheiry et al. 2019). Despite promising outcomes and effectively feasible applications of ML, the study has the potential for further research with other considerations and using technology to cater for AI (such as using chatbots). We suggest, with smart AI-based agents (in the form of a chatbot) could be effectively used to predict CS for a better user experience of virtual reality (Zaidi et al. 2020). Also, techniques like natural language processing (NLP) techniques would offer engaging immersion and relaxation options for VR as a relaxation application (Fagernäs et al. 2021). Finally, we believe more data could be collected from larger datasets to potentially get higher accuracies for predictions using ML algorithms. It would be good to see how ongoing research in ML would introduce new and effective algorithms which would further facilitate the process of understanding CS. Future of VR's success lies with the researchers and developers and further research addressing CS needs to be done to broaden the horizon in tackling CS for VR users (Wu et al. 2021; Martirosov et al. 2022; Oh and Son 2022; Souchet et al. 2022).

## 5 Conclusion

Understanding and alleviating CS are the elements of ongoing research for VR development in various fields. To strengthen the development strategies for interactivity, engagement and usability of VR technology, we proposed an approach that uses a smart (AI) system for CS prediction and identification using predictive ML algorithms. The outcome of this study would predict possible different levels of CS among people using VR technology. The methods proposed were able to predict CS with high accuracies on the test dataset (93%). Both DT and SVM have had high test accuracies but since looking at the train accuracies of these two algorithms, DT has had a better performance in comparison with the other methods. The proposed method can be used to create an expert system to predict CS among VR technology users.

As per their tendency, ML algorithms can continue to perform and learn more with wider attributes along with SSQ to determine the possible occurrence of CS. The possible additional attributes could be about the VR system, VR environment complexity, user's awareness and experiences with the technology; and the user's non-cybersickness/ non-vertiginous dizziness symptoms, for example, persistent postural and perceptual dizziness.

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**Data availability** Previously reported simulator sickness questionnaire-based quantitative data were used to support this study and are available at [https://doi.org/10.13020/a9w0- 8k04]. These prior studies (and datasets) are cited within the text as references (Curry et al. 2019). The data used can be accessed directly at: https://conservancy.umn.edu/handle/11299/209152, which is Published Date 2019–12-16 under the license—CC0 1.0 Universal.

## Declarations

**Conflict of interest** The authors have no conflict of interest to declare.

**Ethical approval** Ethical review and approval were not requested for this study by the authors' institution.

**Consent to participate** Informed consent was obtained from all the participants involved in the study.

**Consent for publication** Not applicable.



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