Augmented and Virtual Reality Games for Occupational Safety and Health Training: A Systematic Review and Prospects for the Post-Pandemic Era

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Abstract—In recent decades, the usage of augmented reality (AR) and virtual reality (VR) games for safety training and rehabilitation has grown exponentially. However, no systematic literature review of the research trends in augmented and virtual reality (AR/VR) for Occupational Safety and Health (OHS) training has been carried out. The authors conducted a comprehensive review of the relevant literature published between 2016 and 2020. This analysis was guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). The Scopus database contained 1031 records. However, only 12 papers matched the inclusion criteria and were included in this review. According to the findings, the use of augmented and virtual reality for safety training and rehabilitation has been progressively growing. With robust research trends in this field—in the post-pandemic era, the use of augmented reality and virtual reality games has promising potential, especially for safety training and rehabilitation. This study provides critical insights into how augmented reality and virtual reality may impact the future of safety training and rehabilitation at the workplace.

Keywords—COVID-19, hazard, occupational exposure, AR, VR

1 Introduction

Preventing accidents and ensuring the health and safety of employees at work are extremely important. Meanwhile, augmented reality (AR) and virtual reality (VR) allow people to see a representation of real-world settings even when they are not physically located there [1]. As a result, the use of AR and VR for occupational safety training and rehabilitation has increased over recent decades, most notably in the workplace. It has been extensively used in the context of Occupational Safety and Health (OHS) to ensure safe working conditions in industrial settings and work environments [2]. Therefore, numerous research has been undertaken on the use of AR and VR to improve safety training and rehabilitation [3]. For instance, Aromaa et al. [4] developed a work injury scenario using VR for occupational and process safety training, as well as risk prevention. The advances in AR and VR have enabled the development of novel approaches within the fields of accident prevention and occupational health.

Meanwhile, a gamification-based approach incorporates and adapts gaming concepts and ludic methods into a more serious training environment. The elements of reward and punishment in the gamification approach make serious learning activities interesting and fun [5]. Gamification is increasingly being utilized to educate participants in Occupational Safety and Health training on various aspects of workplace safety and risk. Prior research has established that gamification has been successfully used as an instruction delivery technique in the fields of safety, health and rehabilitation [6][7].

However, even though scholars have conducted systematic reviews of the literature on computer-based interventions for occupational safety and health, none have examined the use of augmented reality in the development of AR and VR games for safety training and rehabilitation. The authors propose to conduct a critically necessary systematic evaluation that identifies research trends regarding the impact of AR and VR games on safety training and rehabilitation. The following key contributions are made by this systematic review:

- A quantitative study of the published data on the topic.
- A complete systematic evaluation of the existing methodologies and models for developing AR/VR tools for OSH purposes.
- A deeper understanding of emerging trends and recommendations for future investigations.

Thus, the goal of this research is to conduct a systematic literature review of the existing academic publications on AR and VR games for safety training and rehabilitation. The review also aims to highlight research trends and gaps in selected research works. The following research questions (RQ) were developed as part of this work:

- RQ1: What publication trends can be identified?
- RQ2: What categories of solutions are offered by AR/VR games?
- RQ3: What specifications and types of AR systems are used in the developed solutions?
- RQ4: Which of the game solutions provided is relevant to workplace safety?
- RQ5: What type of safety training is evident and in which category of control measures does it belong?
- RQ6: What details are available about build-and-test in a developed system?
- RQ7: What challenges can be identified during game testing session?
- RQ8: What are the issues related to/VR gesture recognition?
- RQ9: What are the advantages of the developed AR/VR games?

2 Methodology

A thorough study was made of the literature available from the Scopus indexing database that appeared to have strong connections to the utilization of AR and VR in safety training and rehabilitation. The search was completed in June 2021. To ensure that the appropriate publications were reviewed, the following document types were excluded: book chapters, conference reviews, books, editorials, data papers, letters, and notes (Table 1). The analysis was only performed on the included journal papers and conference proceedings.

Table 2 shows the advanced search query string used to extract literature from the Scopus indexing database.

Table 1. The inclusion and exclusion criteria

Criteria	Inclusion	Exclusion
Timeline	2016-2020	<2016 and 2021
Document type	Journal article, Conference paper	Book chapter, Review, Conference review, Book, Editorial, Data paper, Letter, Note
Publication stage	Final	Article in press
Exact keywords	augmented reality, mobile, app, apps, game, games, gamification, training, e-learning, education, simulation, occupational risks, accident prevention, safety, rehabilitation, hazards	[Other than mentioned in the inclusion criteria]
Source type	Journal, Conference proceeding	Book series, book, trade journal
Language	English	[Other than English]

Table 2. Advanced search query string

Database	Advanced search query string
Scopus	TITLE-ABS-KEY (("Augmented Reality" OR ar) AND (mobile OR app*) AND (game* OR gamifi*) AND (training OR e-learning OR education OR simulat*) AND ("Occupational Risks" OR "Accident Prevention" OR safety OR rehabilitation OR hazards) AND NOT (review)) AND (LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2018) OR LIMIT-TO (PUBYEAR , 2017) OR LIMIT-TO (PUBYEAR , 2016)) AND (LIMIT-TO (DOCTYPE , "cp") OR LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (LANGUAGE , "English"))

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) criteria were utilized to guide the review [8]. Initially, 1031 papers were discovered using the keywords provided above. Based on their titles and abstracts, 1000 publications were manually removed; hence, the total number of entries became 31. Finally, only 12 research publications matched the inclusion criteria and were thus acceptable for use in the analysis and in response to the research questions. Figure 1 depicts the PRISMA flow diagram.

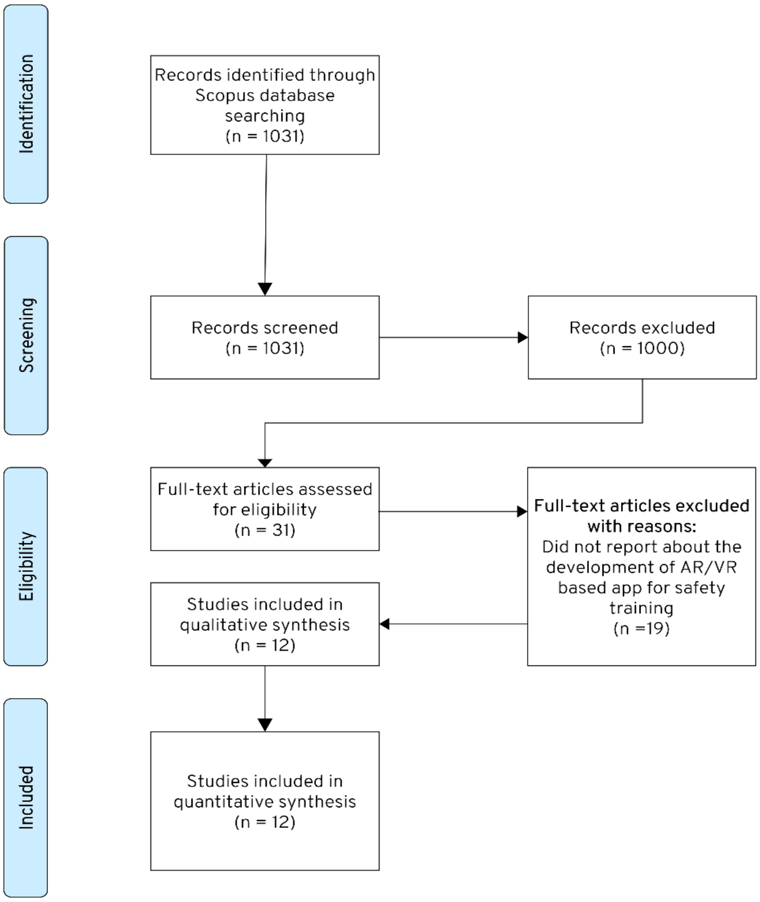

Fig. 1. PRISMA Diagram (adapted from Moher et al. [8])

3 Results

3.1 Publication trends

RQ1: What publication trends can be identified?

Only one paper was published in 2016, doubling to two a year later. In 2018 and 2019, the numbers rose to three and four, respectively. However, in 2020, the number decreased to two (see Figure 2). Table 3 shows the document types and the author's country of origin. Nine of the 12 works were conference proceedings papers, while three were journal articles. With three publications, China was the most productive country, followed by Greece (two papers). The remaining seven countries each produced a single paper on a topic related to this field. Table 4 shows the main summary matrix of the reviewed papers.

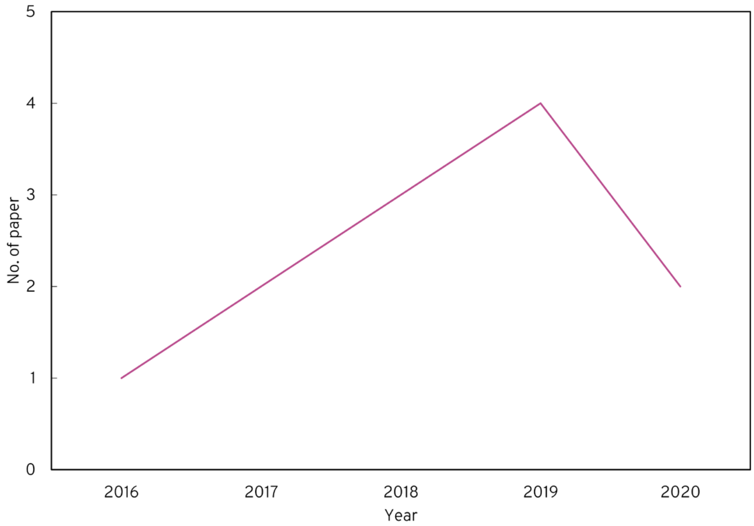

Fig. 2. Paper publication trends from 2016-2020

Table 3. Document types and author's country of origin

Document type	Frequency
Conference proceedings	9
Journal article	3
Country	
China	3
Greece	2
Canada	1
Japan	1
United Kingdom	1
Spain	1
South Korea	1
Brazil	1
Italy	1

Table 4. The main summary matrix

Authors	Year	Country	Title	Technology		
				AR	***VR***	***Hybrid***
Xue et al. [9]	2018	China	Gesture Interaction and Augmented Reality based Hand Rehabilitation Supplementary System	✓		
Chen et al. [10]	2020	China	Lower Limb Balance Rehabilitation of Post-stroke Patients Using an Evaluating and Training Combined Augmented Reality System			✓
Ying & Aimin [11]	2017	China	Augmented reality based upper limb rehabilitation system	✓		
Ocampo & Tavakoli [12]	2019	Canada	Visual-Haptic Colocation in Robotic Rehabilitation Exercises Using a 2D Augmented-Reality Display	✓		
Hatzigiannakoglou & Okalidou [13]	2019	Greece	Development of an auditory rehabilitation tool for children with cochlear implants through a mobile-based VR and AR serious game		✓	
Kawai et al. [14]	2016	Japan	Game-based evacuation drill using augmented reality and head-mounted display	✓		
Charalampous et al. [15]	2020	Greece	Designing and Developing a VR Environment for Indoor Fire Simulation		✓	
Beever et al. [16]	2019	United Kingdom	Assisting Serious Games Level Design with an Augmented Reality Application and Workflow	✓		
Vera et al. [17]	2018	Spain	A hybrid virtual-augmented serious game to improve driving safety awareness			✓
Moon & Kwon [18]	2019	South Korea	Developing a puzzle using the mixed reality technology for the elderly with mild cognitive impairment	✓		
Ginja [19]	2018	Brazil	Applications of virtual reality in the practice of para-badminton		✓	
Crepaldi et al. [20]	2017	Italy	Supporting rehabilitation of ADHD children with serious games and enhancement of inhibition mechanisms		✓	

3.2 Solutions offered by AR/VR games

RQ2: What categories of solutions are offered by AR/VR games?

From the 12 articles selected, four major problems in various application fields were identified and addressed by researchers. The following application fields were stated: (i) rehabilitation; (ii) safety training; (iii) safety awareness; and (iv) health deterioration prevention. The rehabilitation systems already developed can be further enhanced for use with hands [9], lower limbs [10], upper limbs [11], cognitive disabilities [12], auditory problems [13] and handicapped patients [19]. In terms of safety training, authors have focused on disaster evacuation drills [14], fire drills [15] and indoor fire spreading emergency simulations [16]. Only one paper was published on raising safety awareness while driving [17]. Moon and Kwon [18] and Crepaldi et al. [20] addressed health deterioration prevention issues faced by the elderly in reducing dementia and when managing behavioral issues in ADHD children, respectively. The above-mentioned information is presented in Figure 3:

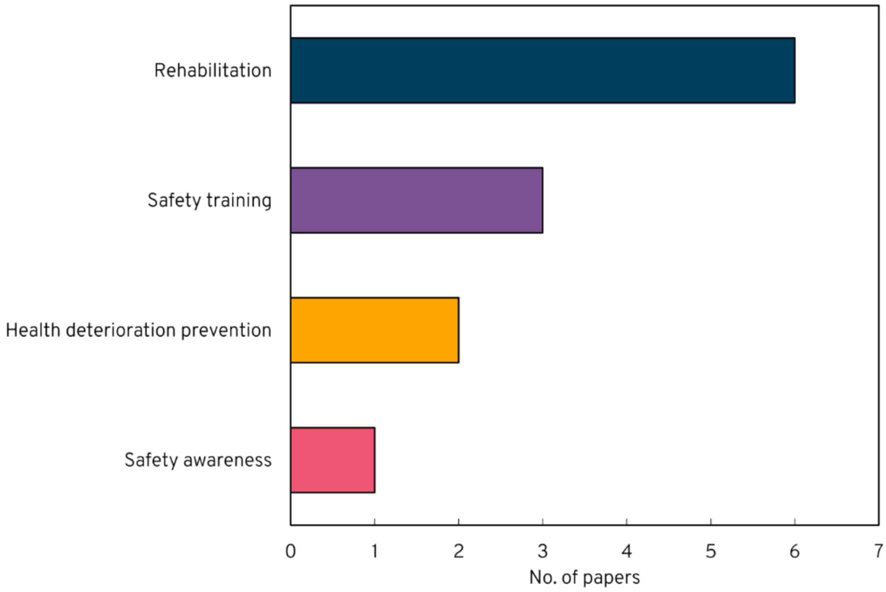

Fig. 3. Number of papers based on the fields of applications

Meanwhile, the solutions to the problems outlined in the application fields above are based on AR, VR and hybrid. AR has been applied in developing multi-purpose hand rehabilitative treatment [9], multisensory feedback in upper limb rehabilitation systems [11], visual haptic collocation [12], improved Game-Based Education Drill (GBED) [14], a digital real-world indoor model for a serious game concerning fire safety training [16] and a dementia prevention puzzle program [18]. VR has been used to develop mobile-based serious games for auditory rehabilitation [13], indoor fire drill programs [15], para-badminton simulation games [19] and dual pathway model-based serious games for ADHD children [20]. The hybrid technology of AR-VR has also been implemented in two studies, namely the development of lower limb post-stroke rehabilitation treatment [10] and a driving safety awareness serious game [17].

3.3 Systems specifications and types of AR

RQ3: What specifications and types of AR systems are used in the developed solutions?

Table 5 illustrates the software tools used in developing the games.

Table 5. Software tools used in the development of the games

Paper	Software tools														Types of AR	
	Apache	MySQL	Unity 3D	C#	Java	MATLAB	Simulink	ArUco	Blender	FORTRAN	Visual Studio	Vuforia API	Steam VR	XML	Marker-based	Markerless
AR-Based Solutions																
Xue et al.[9]	✓	✓	✓	✓	✓										✓	
Ying & Aimin[11]															✓	
Ocampo & Tavakoli[12]			✓			✓	✓									✓
Kawai et al.[14]			✓					✓							✓	
Beever et al.[16]				✓					✓	✓					✓	
Moon & Kwon[18]			✓								✓	✓			✓	
VR-Based Solutions																
Charalampous et al.[15]			✓						✓	✓						
Ginja[19]			✓	✓									✓			
Crepaldi et al.[20]			✓											✓		
Hybrid (AR/VR)-based solutions																
Chen et al.[10]			✓													✓
Vera et l.[17]															✓	

From the final 12 publications, four studies developed VR-based solutions, six worked on AR-based solutions and two were hybrid-based using AR/VR. Unity 3D is the most common type of software used in the development process, with a total of eight papers using it. Both marker and markerless AR types were implemented in the AR-based and hybrid-based studies, with most works using marker-based types. Table 6 shows the hardware used in developing the games.

Table 6. Hardware used in the development of the games

Hardware	Paper
Leap Motion	Xue et al. [9]
	Charalampous et al. [15]
InFocus IN116A projector	Ocampo & Tavakoli [12]
Oculus Rift, Ovrvison Pro	Kawai et al. [14]
Holographic Lens	Moon & Kwon [18]
VR headset	Hatzigiannakoglou & Okalidou [13]
Kinect V2	Chen et al. [10]

Seven works were identified as requiring specific hardware to develop the proposed solutions. Leap Motion was the most common type of hardware. Two related papers, by Xue et al. [9] and Charalampous et al. [15], reported its usage in AR-based gesture recognition technology with virtual buttons and VR para-badminton games, respectively.

3.4 Game solutions and workplace safety

RQ4: Which of the game solutions provided is relevant to workplace safety?

Out of the twelve papers reviewed, six are relevant to workplace safety while the rest are related to lifestyle or genetics. Workplace safety in this context refers to potential workplace issues affecting employed individuals or groups. The papers and their relevance to workplace safety issues are listed in Table 7.

Table 7. Workplace safety issues related papers and their solution

Safety issue	Solution	Paper
Ergonomic	Improvement in the rehabilitation training process	Xue et al. [9]
		Ying & Aimin [11]
Fire safety	Improvement in indoor fire response and evacuation training	Kawai et al. [14]
		Charalampous et al. [15]
		Beever et al. [16]
Road safety	Improvement in road safety awareness training	Vera et al. [17]

The safety issues were categorized into ergonomic, fire and road safety issues. Ergonomic issues are related to mismatches between work and workers [21]. Fire safety issues are related to the lack of protection from fire [22], while a road safety issue means a lack of protection if a road accident occurs [23].

3.5 Types of safety training and categories

RQ5: What type of safety training is evident and in which category of control measures does it belong?

In this review, the training was divided into two types: physical training and cognitive training. Physical training is a series of actions undertaken by individuals or a group to improve psychomotor skills or muscle memory, while cognitive training is a series of actions undertaken to improve developmental skills and knowledge acquisition. Control measures, on the other hand, can be classified into two types: preventive control measures and mitigative control measures. The former are actions taken to reduce the potential exposure to hazards, while the latter are actions taken to protect someone from, or reduce the severity of, harm after exposure to hazards.

Out of the twelve papers reviewed, five papers were found to focus on physical training and another five papers focused on cognitive training, while the rest consisted of a combination of both types. In terms of the control measures category, four papers were classified as referring to preventive control measures, two papers were classified as referring to mitigative control measures and the rest were not applicable. The papers with the respective types of training and categories of safety control measures are listed in Table 8.

Table 8. Types of safety training and categories of safety control measures

<table>
<tr><th>Type of Training</th><th>Paper</th><th>Control category</th></tr>
<tr><td rowspan="5">Physical</td><td>Xue et al. [9]</td><td rowspan="2">Mitigative</td></tr>
<tr><td>Ying & Aimin [11]</td></tr>
<tr><td>Chen et al. [10]</td><td rowspan="3">NA</td></tr>
<tr><td>Ocampo & Tavakoli [12]</td></tr>
<tr><td>Hatzigiannakoglou & Okalidou [13]</td></tr>
<tr><td rowspan="5">Cognitive</td><td>Charalampous et al. [15]</td><td rowspan="3">Preventive</td></tr>
<tr><td>Beever et al. [16]</td></tr>
<tr><td>Vera et al. [17]</td></tr>
<tr><td>Crepaldi et al. [20]</td><td rowspan="2">NA</td></tr>
<tr><td>Moon & Kwon [18]</td></tr>
<tr><td rowspan="2">Physical + Cognitive</td><td>Kawai et al. [14]</td><td>Preventive</td></tr>
<tr><td>Ginja [19]</td><td>NA</td></tr>
</table>

The types of training were categorized into physical, cognitive and a combination of both. Physical training relates to planned activities intended to improve one's physical fitness [24]. Cognitive training is related to planned activities intended to improve cognition and memory [25].

3.6 Build-and-Test in a developed system

RQ6: What details are available about build-and-test in a developed system?

The performance of each developed system was tested through the instruments and processes explicitly designed for the system, using AR, VR and Hybrid (Mixture of AR and VR) technologies. The instrument's design requires either physical training or cognitive training or both physical and cognitive training. The designs of the developed systems, as reported in the 12 papers in this SLR, are shown in Table 9.

Table 9. Developed system applications and technologies

Applications	AR	VR	Hybrid
Rehabilitation	Xue et al. [9], Ying & Aimin [11], Ocampo & Tavakoli [12]	Hatzigiannakoglou & Okalidou [13], Ginja [19]	Chen et al. [10]
Safety Training	Kawai et al.[14], Beever et al. [16]	Charalampous et al. [15]	NA
Safety Awareness	NA	NA	Vera et al. [17]
Health deterioration prevention	Moon & Kwon [18]	Crepaldi et al. [20]	NA

As shown in Table 9, the developed systems were categorized into three applications, based on the respective implementation of AR, VR and hybrid technology. The implementation of these technologies requires thorough system build-and-test stages. The build-and-test stages in a system design were identified; they include the pre-data process, the physical concept (use of a physical or hardware-aided model or design), the digital design or prototype (pre-game computer-aided or software-aided design), and the AR, VR or Mixed Technologies games. These are important in validating the usability of the developed systems, as shown in Table 10.

Table 10. Build-and-test stages in the developed systems

AR/VR game implementation	Pre-Data Collection	Physical Concept	Digital Design	No. of Participant	Paper
AR Cup training: Moving a virtual cup to a specified ring	✓	✓	✓	10	Xue et al. [9]
AR evaluation of scene and VR training scene of the system of a 'Touch the Soccer Ball' Simulation	✓	✓	✓	18	Chen et al. [10]
Simulated rehabilitation scenario environment using 2D spatial AR system.		✓	✓	10	Ocampo & Tavakoli [12]
Children's Virtual Reality 3D game using VR headsets		✓		14	Hatzigiannakoglou & Okalidou [13]
The participants were thrown into an earthquake scenario and wore Oculus Rift devices with Ovrvision	✓	✓	✓	17	Kawai et al. [14]
Subjects used LevelEd AR application to model tasks in AR and scan the task loca-		✓	✓	18	Beever et al. [16]

tions					
This hybrid serious game is based on the 'Game of the Goose', which features a board with a track and players move a virtual token			✓	285	Vera et al. [17]
HoloLens tracks users' eye movements.		✓	✓	21	Moon & Kwon [18]
Leap Motion is used to capture hand positions and movements for badminton game training		✓	✓	14	Ginja [19]
A serious game, named Antonyms, is played with a touch screen	✓		✓	30	Crepaldi et al. [20]

Not all the papers applied build-and-test stages completely in their study. Some studies focused on existing AR or VR games as part of the process of developing new systems. In the study by Ying & Aimin [11], the sampling group is not mentioned. However, the system implemented AR games such as tea pouring games, simulated driving and brick breakers, which included physical concepts and digital design stages. Meanwhile, Charalampous et al. [15] conducted pre-data collection and digital design to support the system development of a VR environment for an indoor fire simulation in their build-and-test stages. However, they did not mention in detail the number of participants in their study. Chen et al. [10] stated that a group of healthy volunteers tested the system as they would be the key indicators of the system's validity and usability once it is applied to post-stroke patients. To make improvements, the authors planned to conduct a controlled trial with post-stroke patients to test the system's usability and discomfort symptoms and prove the validity of customisable training.

3.7 Challenges in AR/VR game testing

RQ7: What challenges can be identified during game testing session?

Developing a new system using AR/VR/MR technology requires the researchers to design a systematic experimental process and build a research model or design that meets the purposes of the study. Results of running activities are significant as they are used to check the usability of a system. However, several challenges were also mentioned in the 12 reviewed papers. In the study by Xue et al. [9], the results of the game analysis met the need for natural human-machine interaction. However, technical difficulties occurred in tracking and detecting the gestures of the participants. According to Chen et al. [10], data related to patients' movement and balance ability would provide therapists with more scientific references about the patients.

Furthermore, evaluation results allow therapists to customize different difficulties in VR-based rehabilitation training programs depending on the patients' various lower limb balance abilities. In the study by Ying & Aimin [11], performance data from patients playing the designed rehabilitation games allowed the therapist to guide the patients professionally and at a distance using a remote therapist system. However, more rehabilitation games should be provided to precisely advise patients about accurate movements, which would make the system more reliable.

In the study by Ocampo & Tavakoli [12], games were tested smoothly. The participants presented their best performance when completing the game tasks in the form of spatial AR (a visual frame and a hand frame), with or without haptics. According to Hatzigiannakoglou & Okalidou [13], mobile-based software used VR and immersive technology to help children with cochlear implants; this improved their auditory skills. All the children were enthusiastic about the games, proving that this product design would be suitable for an Auditory Training Tool. Kawai et al. [14] explained that a new GBED system was appropriate for disaster education since it could enhance the visual reality of the previous system. However, some problems remained, such as AR material presentation failure and 3D sickness suffered by participants that caused difficulties in moving. In the study by Charalampous et al. [15], the proposed serious game revealed that the first two lists extracted from the dataset helped the authors to calculate a complete burn index (an object's mass zeroes out) and calculate the total time of an object needs to lose its whole mass.

According to Beever et al. [16], the system testing results showed that a LevelEd AR application proved more accurate than a Structure sensor and consumed less time than a tape measure. The problem of drift occurred when the device lost track of its position in the real world and became out of sync with the virtual world, which caused a minor inaccuracy during the task. Vera et al. [17] reported that the use of a serious game application was a plausible method of engaging people in driving safety issues.

Meanwhile, developing an MR puzzle program that included 3D images to enhance brain activation among the elderly while solving a puzzle was an effective tool in improving the subjects' cognitive functions, as reported by Moon & Kwon [18]. Despite this, the major challenge to this system was that a few elderly users surrendered quickly when they could not fit puzzle pieces by themselves or because they were not interested in this game. In Ginja [19], since some mechanics had not been completed, the system had not been certified by para-badminton athletes. Lastly, the serious game introduced by Crepaldi et al. [20] described how impulsivity and inattention were addressed during gameplay tests with a control group of ADHD children.

3.8 Issues related to AR/VR gesture recognition

RQ8: What are the issues related to AR/VR gesture recognition?

The rate of correct gesture recognition was high, according to the main gesture discrimination test used by Xue et al. [9], essentially meeting the need for natural human-machine interaction. The 3D rendering engine used was Unity3D, which allowed on-screen scenes to run smoothly. The server-side was written in Java and its framework, while the gesture response was accurate and timely. The system's data transmission was stable, and the effect was satisfactory.

According to Ginja [19], image processing of Leap Motion data can be performed using an API for Unity 3D, which is an object-oriented programming language. The

Leap API has classes that store and track data which can be used in games. Hand, Gesture, Frame and Controller are a selection of the classes used in gesture recognition. Some scripts were written to recognize more complex gestures, such as grabbing a racket and hitting a ball with the racket. These gestures are a hybrid of Gesture methods with some modifications. This application does not show the user's hand model to improve precision. A hand model could unintentionally collide with the ball. When the user's hand is closed, the hand position on the racket, the velocity and the rotation are displayed. When the player releases the racket, the object reverts to its original position, which is visible to the player. A comparison of two parameters is used to recognize grip gestures: the *Grabstrength* variable and the distance between the fingers and the palm. When *Grabstrength* returns to 1 and the fingers are very close to the palm, the script interprets this as the player's hand being closed and moves the racket accordingly. The `ToUnityScale()` function from the Leap API is used to make this conversion.

3.9 Advantages of the developed games

RQ9: What are the advantages of the developed AR/VR games?

The most important aspects of the work of Chen et al. [10] are the quantitative evaluation and the application of the evaluation results to customize rehabilitation training. The authors proposed an AR/VR-based solution for post-stroke patients' lower limb balance rehabilitation, which combines traditional Bobath therapy and AR/VR to achieve post-stroke patient evaluation and rehabilitation training. Ying & Aimin [11] also used this solution in the field of rehabilitation. To achieve virtual object registration and tracking, the system employs a computer vision-based method. By operating marker-attached objects, the patient can interact with the system. Patients experience a multisensory and interactive form of rehabilitation.

Meanwhile, Ocampo & Tavakoli [12] compared the effects of collocated and non-collocated visual feedback in a rehabilitation setting. The results revealed that the effect of visual-haptic colocation improves task performance, particularly for those under cognitive load. The structure of a new auditory rehabilitation tool and the results of software usability testing were presented by Hatzigiannakoglou & Okalidou [13]. Virtual reality, immersive technology and VR headset devices have all been deemed viable options for developing an auditory training tool.

According to Kawai et al. [14], a new GBED system improved the visual reality of the AR materials presented in the GBED by combining a marker-based AR library (ArUco) with a binocular opaque HMD (Oculus Rift). It was discovered that the new system could improve visual reality and motivate participants to learn about disaster response through a trial experiment. Charalampous et al. [15] only used the mass-loss rate and time sequence of the simulation's exported dataset to support trainees during their learning period, a process which could be adopted by firefighting organisations. Beever et al. [16] demonstrated a prototype application that allowed users to capture indoor models of real-world locations for use in serious and entertainment games, as well as passive haptics and substitutional reality.

Meanwhile, Vera et al.[17] developed a serious game aimed at increasing driving safety awareness. The game is both fun and useful, and it adheres to the principle that learning through fun is always easier than learning through tedious lessons. An MR puzzle program with 3D images to enhance brain activation while solving a puzzle was effective in improving cognitive function, as described by Moon & Kwon [18]. This puzzle program was tested with the elderly, most of whom found it enjoyable and simple to use. Crepaldi et al. [20] described the design and development of Antonyms, a serious game for the treatment of ADHD in children. The game used the Dual Pathway Model approach, which is characterized by a single plot that happens over three scenarios and requires the player to complete difficult tasks.

4 Discussion: Prospects for the post-pandemic era

4.1 Promising trends for pandemic-related research

Consistent with the current findings, Li et al. [26] also stated that AR/VR benefits both researchers and industry practitioners through the use of cutting-edge VR/AR for safety purposes. The findings also indicate interesting trends in the use of AR and VR games for safety training and rehabilitation that can be investigated in future research, especially in pandemic-related studies. The current study reveals that the phrases 'augmented reality' and 'games' were widely used in occupational safety and health literature in 2016 and that a greater number of studies were conducted thereafter. However, concerns are growing about the viability of augmenting educational and training content with augmented reality—that is, whether translating the information to AR format is worthwhile [27]. Additionally, these findings support the earlier systematic review of 42 publications conducted by Vigoroso et al. [6]. They demonstrated digital games could help operators improve their abilities and safety knowledge.

4.2 Scarcity of comprehensive and effective solutions

Both AR and VR have been deemed useful in various fields, which demonstrates the potential of the technologies implemented. Though AR/VR has been widely applied in studies across multiple disciplines, the number of solutions remains scarce and there is an opening for more advanced software and applications to be created. In terms of safety and health, major opportunities can be explored in future work, whether concerning the limitations of current developments or the authors' suggestions. Moreover, the system requirements and environments listed in the published studies indicate how scholars from various fields of expertise might delve into AR/VR technology with little difficulty. Most of the software needed to develop AR/VR based applications is available free, except when certain libraries or assets are needed, in which case access is via purchase or subscription.

Furthermore, AR has taken the wheel and is poised to take over the automotive industry. VR is currently being used in e-showrooms across the internet to showcase vehicle features, while the technology enables consumers to take online test drives of new vehicles. Vera et al. [17] created a software application that combines different interaction and visualization modes to improve driving safety awareness and learning. For a given set of driving-related situations, multiple users can participate simultaneously and increase their sense of immersion through virtual content. For example, Abdi and Meddeb [28] proposed a new AR traffic sign recognition system (AR-TSR) to improve driving safety and enhance the driver's experience. Spatial data was used to improve accuracy and the authors reviewed studies of the driver's perception and the effectiveness of augmented reality in improving safety while driving.

4.3 Potential for improving workplace hazard controls in the new normal

From the workplace safety standpoint, several technological developments have offered real potential to be applied to improve hazard control measures in the workplace. This is particularly important in the new post-pandemic normal. Training is an element in the control hierarchy, albeit a mostly unreliable one, since it depends highly on one’s capability to maintain and retain information over a long period. The use of AR/VR technology in cognitive training can enhance that capability and decrease the likelihood of future workplace accidents in organizations. It is worth noting that AR/VR can also accelerate the recovery of patients affected by workplace ergonomic issues by reducing the time they take to return to work and productivity, which in turn benefits the family economy, society, and the nation.

4.4 Post-pandemic solutions for medical purposes and healthcare

It has been demonstrated that both VR and AR, as well as the latest technology MR, are experiencing greater attention, especially during the COVID-19 pandemic [29]. They have been adapted into various spheres, including healthcare, education, training, the military, and manufacturing. For example, by implementing AR and VR, researchers have identified innovative ways for health practitioners to build connections with their patients during the pandemic, for example, by providing remote and personalized care [30]. However, disruptions to healthcare systems and the need for physical distancing seem to require extensive experience of digital health solutions and have the potential to expand rapidly once the pandemic passes. However, the long-term use of digital health solutions is highly dependent on addressing certain challenges [31].

Furthermore, AR and VR technologies are useful tools in the rehabilitation process. A rehabilitation training project with different levels of difficulty makes the rehabilitation process more enjoyable and challenging [9]. Such a system can help a professional therapist to guide the treatment of multiple patients simultaneously, reduce the reliance of the rehabilitation treatment process on the therapist and provide treatment at any time and place. According to Chen et al. [10], an AR-based evaluation module allows the limits of patients' lower limb balance abilities to be visualized and provides quantitative data to the respective therapists. Thus, rehabilitation therapists can create personalized VR training games based on this information. Therapists can easily obtain a patient’s information and offer the patient professional guidance using augmented reality games [11]. With human users participating in a rehabilitative game, Ocampo & Tavakoli [12] integrated spatial AR into robotic rehabilitation to provide colocation between visual and haptic feedback.

4.5 Applications in distance education and virtual training

Several studies have investigated the implications of AR and VR in broad or specific fields. AR and VR have been widely used in distance education and virtual training within several disciplines in which their efficacy has been demonstrated [32], despite various constraints in instructional design [33]. Graphic computing and object recognition technologies could help children visualize the real world using virtual objects. Improved performance, increased motivation and engagement, as well as increased collaboration among learners, are some positive implications of using AR in education [34]. Virtual reality is being used in education to transport children to different historical eras or train healthcare workers. Engineering education, medical education, space technology and mathematics, general education and special needs education are a selection of the fields in which VR is useful. Visual support, enhanced learning interests and authentic learning opportunities were among the benefits of VR in language learning, as Shadiev and Yang [35] identified.

Meanwhile, AR and VR technology will continue to enhance Online Distance Learning (ODL) sessions to engage learners actively, especially mid- and post-pandemic [36]. The capacity of AR and VR to create remote and in-depth learning environments provides an appropriate opportunity for governments and schools to take advantage of this critical situation. Current AR and VR technologies are sufficiently advanced to provide remote collaborative classrooms and allow large groups of students to congregate and learn while minimizing the risk of exposure [37]. In the future, mixed reality technologies such as augmented reality and virtual reality can be further investigated to improve user behavior, engagement, and interest [38]. Extensive discussion of how an Augmented Reality-Based apps might be used to enhance occupational safety and health training can be found in [39]. The discussion points mentioned above are summarized in Figure 4:

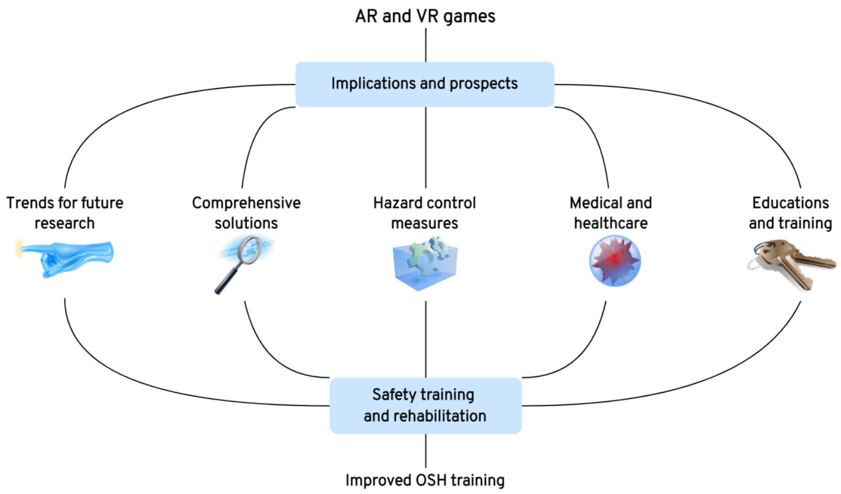

Fig. 4. Implications and prospects of AR and VR games for safety training and rehabilitation

5 Conclusion, limitations, and future work

The use of augmented reality and virtual reality in occupational safety training and rehabilitation has attracted significant attention from the academic community. This paper has systematically reviewed the latest developments and applications of game-based AR/VR games for safety training and rehabilitation. The findings indicate that augmented reality/virtual reality games can potentially be used for OSH training purposes. However, additional comprehensive systematic reviews and meta-analyses are required to reconfirm these findings. This will be particularly important in the post-pandemic era.

However, despite the present paper's substantial findings, several limitations must be addressed. First, this review relied solely on Scopus (due to subscription's restrictions on accessing the Web of Science indexing database). This database created a weakness in the data extraction, compared to the potential collection of data had Web of Science or Google Scholar been used. Second, the review methodology greatly influenced and constrained the findings of the review. The search process may have accidentally excluded suitable candidate papers. Thirdly, this paper was not subject to a more complete review, such as meta-analysis or citation analysis. As a result, the efficacy of the current research may have been jeopardized.

Future work may involve adding a quality assessment of the articles before including them in a review. Additionally, it is recommended to incorporate additional relevant bibliographic databases, such as IEEE Xplore, Google Scholar and Lens.org, to facilitate the retrieval of pertinent literature and obtain a more extensive review. Besides, our research should also be geared more toward the application of AR and VR games in the field of exercise science and fitness.

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