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COMPARE VR VS. CONVENTIONAL TRAINING FOR CONSTRUCTION WORKERS' SAFETY AWARENESS

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ABSTRACT

In recent years, Sri Lanka's construction industry has seen a troubling increase in both fatal and non-fatal accidents, largely attributed to insufficient safety knowledge among workers and deficiencies in the health and safety system. To mitigate these accidents, effective occupational health and safety training is imperative. However, the efficacy of traditional safety training methods has been questioned due to their limited impact on workers' ability to identify and assess risks critically. The lack of experiential training is the primary cause of accidents that could have been easily avoided at construction sites in Sri Lanka. Addressing this gap, there is growing interest in utilising Virtual Reality (VR) as a powerful tool for experiential safety training in the construction sector. VR offer a realistic and safe environment where workers can engage with various scenarios and procedures, enhancing their understanding and awareness of safety protocols. This research explores the effectiveness of VR tools in enhancing safety knowledge and awareness among construction workers through a simulation safety training platform, using VR and PowerPoint methods for data collection. An experiment was conducted with VR and PowerPoint safety training methods as a data collection method. A questionnaire survey was conducted to compare conventional training methods with the VR solution. The results indicate that workers trained in VR environments had better retention of critical information, highlighting the efficiency of VR in providing a safe yet realistic training experience. This research emphasises the potential advantages of the suggested VR safety training methods in improving construction safety knowledge and awareness of construction workers.

Keywords: *Construction Safety, Safety Training, Virtual Reality (VR), Construction Accidents*

1. INTRODUCTION

The construction industry is one of the significant industries subjected to massive health and safety problems which is linked to a dangerous work environment that causes many work-related hazardous, injuries, and diseases for the employees compared with other industries (Kumarasinghe & Dilan, 2022; Risath & Alm, 2017). When considering the Sri Lankan construction industry has reported a higher number of fatalities and injury rates, which is ranked as the 3rd worst among industry groups in Sri Lanka (Risath & Alm, 2017). Every year 2500 to 3,000 accidents are reported to the Industrial Safety

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Division of the Labour Department in Sri Lanka (Ministry of Labour, 2021). Out of those accidents, 40% to 60% were fatal and 30% were construction accidents (Delpachitra & Allis, 2022). As it is clear from much research data, the accident still happens with great frequency and severity and the unsafe working environment in the construction industry of Sri Lanka is still an unsolved problem.

Several reasons can cause safety hazards to construction workers in Sri Lanka. One of the major reasons for that kind of injury is the lack of strong health and safety practices (Kumarasinghe & Dilan, 2022). Shamsuddin et al. (2015) highlighted most of the building construction projects in Sri Lanka experience weak health and safety practices. Shamsuddin et al (2015) described that the inefficiency of current safety training practices is the most influencing factor in causing unsafe work conditions in the building construction industry in Sri Lanka. Further, it highlighted that providing well-structured and highly engaging training for construction employees is essential. The workforce in Sri Lanka can be categorised into management and technical, skilled, semi-skilled, and unskilled, with all workers at risk of injury, death, or illness (Risath et al., 2017). The lack of safety training and awareness among skilled and unskilled workers is a serious issue that needs to be addressed to enhance the occupational health and safety of the construction industry (Vitharana et al., 2015). Although there are various safety training programs implemented in the construction industry, the current safety training has not resulted in an improvement in accident rates in the construction industry (Yoo et al., 2023). Unfortunately, traditional safety training methods such as lectures, pamphlets, presentations, videos, and seminars can be problematic as they often lead to learners being passive and not actively engaging with the material (Elrifaee, 2023). Adami et al. (2021) state that complex tasks using specialised equipment may pose unjustifiable risks to trainees' safety, limiting their exposure to complex situations on site, and the costs associated with acquiring the necessary equipment and materials for the training may be too high. Further identified that On-site training may create unsafe conditions for trainees, a lack of real-time experience, and Training with low engagement such as lectures, presentations and lack of chance to engage with materials (Sacks et al., 2013; Yoo et al., 2023). Even in Sri Lanka, traditional methods have not led to improvements in accident rates and unsafe working behaviours.

New technological tools such as augmented reality, virtual reality, Building Information Modelling, and robots have been used globally for construction safety training (Darda et al., 2023). Many researchers have indicated that construction safety training practices using new technology have been introduced to avoid the unfavourable conditions caused by traditional methods. Xu and Zheng (2021) describe how to develop an immersive and interactive multiplayer-based training platform that incorporates Virtual Reality (VR) technology to improve the safety awareness of workers. Hence, VR-based training can indeed be used to train construction workers effectively to gain the necessary knowledge, skills, and safety behaviour in construction works. Besides, it is the best tool for accident reconstruction, training, and hazard identification by immersing the trainee in an environment as close to the real world as possible (Babalola et al., 2023; Yoo et al., 2023). However, there is a possibility of providing safety training to construction workers using VR technology in the construction industry of Sri Lanka, but there are still no research reports that have been done regarding the initiatives of using these technologies for safety training in the construction industry of Sri Lanka. Therefore, using this new technology for health and safety training in the construction sector of Sri Lanka can be used as an

efficient training method that can be used to enhance the safety knowledge and awareness of construction workers. Moreover, it is crucial to train both skilled and unskilled workers to safely and effectively interact with these new technologies such as VR safety training. Accordingly, this research aims to evaluate the effectiveness of VR tools to enhance the safety knowledge and awareness of construction workers.

2. LITERATURE REVIEW

2.1 HAZARDS IN THE CONSTRUCTION INDUSTRY

The construction industry has created huge employment for workers and makes significant economic contributions yearly (Li, 2018). The construction industry workers are involved in several complex activities while doing construction works on sites. These complexities make the construction industry one of the most dangerous industries that cause several work-related injuries and fatalities across all industries, which makes safety a critical aspect of this industry (Adami et al., 2021; Rokooei et al., 2023). For instance, according to the Korea Occupational Safety and Health Agency (KOSHA), industrial accident status and analysis from 2009 to 2017 showed that fall accidents in the construction industry accounted for 47.7% to 52.1% of fatalities annually (Bao et al., 2022), and also Li (2018) mention that 30% to 40% of fatal industrial accidents in Japan and 50% in Ireland involve construction-related fatalities. Further, Delpachitra and Allis (2022) state that 40% to 60% of were fatal and 30% were construction accidents among those accidents in Sri Lanka. Several factors influence those hazards in the construction sites in Sri Lanka. Those accidents can happen through slipping and stripping at the site, falling from heights, using machines and falling objects from upper floors, lifting and carrying, during machinery works, electrocution, elevator accidents, fire, and explosion (Elrifaee, 2023; Halwathura, 2012; Risath & Alm, 2017). Hence, the construction industry is required to implement proper health and safety practices and enhance the safety knowledge and awareness of construction workers' consideration (Delpachitra & Allis, 2022).

2.2 OCCUPATIONAL HEALTH AND SAFETY TRAINING IN THE CONSTRUCTION INDUSTRY

Construction safety is an important concern that must be considered in the construction industry. Based on the findings of many researchers, the best way to mitigate accidents in construction sites is through better education and safety training of construction workers (Halwathura, 2012; Rita Yi Man Li, 2018; Rokooei et al., 2023; Yoo, 2023). Therefore, conducting proper occupational health and safety programs in the construction industry is an essential area that needs to identify worksite hazards and mitigate the risk of accidents occurring in the construction industry (Chellappa et al., 2022). Construction workers have a significant influence on their safety by deciding to either embrace or avoid risks through their actions. Through proper safety training, construction workers can improve their skills in the ability to identify risks and their subjective analysis of the magnitude of those risks (Sacks et al., 2013). Therefore, it is important to ensure that safety training is interactive and engaging because those strategies can ensure that employees are paying attention to the information and improve their awareness of the subjects being discussed (Elrifaee, 2023).

2.2.1 Role of Training for Construction Safety

According to Yoo et al. (2023), the main role of safety training is to introduce hazards in construction sites and ways to prevent accidents from happening therein. Traditional and computer-based methods are used to enhance employee behaviour and knowledge acquisition. Participatory safety training, which involves active participation and dialogue, is more effective than passive approaches including lectures, presentations, and videos (Burke et al., 2011). Nonetheless, both strategies have been linked to enhanced worker behaviour in terms of safety and health, while more engaging training methods have shown correlations with increased knowledge acquisition and decreased instances of reported accidents and injuries (Burke et al., 2006). These methods can lead to increased knowledge acquisition and decreased accidents and injuries (Nykänen et al., 2020). Hence, effective and efficient Safety training improves individuals' ability to assess hazards and associated risks (Sacks et al., 2013).

2.2.2 Safety Training Methods and their Effectiveness

There are different methods for safety and health training, varying from less engaging to more engaging methods. Burke et al. (2006) found that both engaging (Active strategies), and non-engaging training (Passive strategies) methods improved trainees' behavioural performance. However, active participation in engaging training led to improved knowledge acquisition and reduced accidents. Robson et al. (2015) found that highly engaging training was more effective when the severity of hazardous events was high.

Table 1: Safety training methods
Source: (Burke et al., 2006; Gao et al., 2019; Goh et al., 2015)

Less engaging training method	More engaging training method
Videos	Behavioural modelling
Manuals without exercises	Augmented reality training (AR)
Lectures with minimal interaction	Virtual reality training (VR)
Computer instruction with no interaction	Hands-on training
Feedback and discussion	
Pamphlets	

One of the most effective training methods is participatory training, which has been widely accepted, as adult learners are identified as 'problem-centred' and 'solution-driven'. Nevertheless, the majority of training programs in use currently are inadequate at fulfilling these requirements effectively. According to Burke et al. (2006), they lack engagement and might not optimise the acquisition and retention of knowledge. Many research studies have shown that improving occupational health and safety training appropriately is an important phase (Cha et al., 2012; Huang et al., 2011; Manca et al., 2013; Read et al., 2012). The best way to train is to simulate real tasks and obtain experience (Goldenhar et al., 2001). which illustrates a hierarchy of teaching styles and their effectiveness for trainees. It indicates that Real-life tasks and representative simulations (VR-powered training) are the most effective learning styles. In contrast to passive learning methods, which are less effective, particularly for adult learners, active and participatory training frequently possess a higher level of comprehension activities (Kowalski & Vaught, 2002). Participatory training brings a realistic aspect to safety training that helps trainees relate to conditions and regulations in real-life situations. They learn how to react to life-or-death situations in an 'it can happen to you' scenario.

Accordingly, many pieces of research have shown that the more engaging a method of training, the greater the effects of safety and health training on knowledge acquisition and retention (Adami et al., 2021).

2.3 CURRENT SAFETY PRACTICES IN SRI LANKA

Sri Lanka's construction sector has grown significantly, yet ensuring health and safety remains a major concern, particularly in the building construction segment (Shang et al., 2012). Many researchers found that failure to safety rules, lack of adequate safety procedures and precautions, insufficient safety awareness, lack of communication (Bandara & Perera, 2022), insufficient safety knowledge regarding the handling of machinery, and equipment and neglect to work with simple procedures on the construction site are the higher average causes of occupational accidents occurring in the construction industry in Sri Lanka (Kumarasinghe & Dilan, 2022; Perera et al., 2017). In addition, factors such as inadequate supervision, insufficient training, worker reluctance, lack of safety equipment, and low education levels contribute to unsafe conditions in the construction industry (Halwatura & Jayatunga, 2012). Further, Vitharana et al. (2015) mentioned that the impact of workers' safety attitudes and safety training even though workers' unwillingness to follow safety norms has been identified as a cause of poor safety practices. Research shows that Sri Lanka's construction industry faces unique challenges, with safety practices below acceptable standards. Therefore, to mitigate accidents in the construction industry, contractors can develop safety programs, change work orders, and make safety equipment mandatory are better safety practices to reduce construction-related accidents (Delpachitra & Allis, 2022). Therefore, it is important to consider Proper safety management in the construction industry.

2.4 BARRIERS AND CAUSES FOR POOR SAFETY PRACTICES IN SRI LANKA

Construction workers in developing countries including India, Pakistan, and Sri Lanka are often unqualified and unskilled, leading to high-level accidents in the workplace (Li, 2018). The main reasons for those high-level construction accidents are a lack of safety attitude and the behaviours of the construction workers and a lack of knowledge and awareness of safety (Shamindi & Vithana, 2022). Further, the Sri Lankan construction industry faces a language barrier (English and technical words related to OSH) due to low education levels among workers, making it difficult for them to understand occupational health and safety training (Halwatura & Jayatunga, 2012). Despite safety training being implemented in Sri Lanka, its efficiency is low and there are drawbacks to current methods. To improve safety, proper safety training programs should be introduced, mixed with new technologies, to provide high-engaging training to construction workers (Shamindi & Vithana, 2022). This will help them identify potential hazards and take appropriate action, resulting in a safer workplace.

2.5 SAFETY TRAINING WITH NEW TECHNOLOGIES IN THE CONSTRUCTION INDUSTRY

The construction industry has seen a surge in automation and robotics, aiming to address safety concerns, and labour shortages, and enhance productivity. Safety training technologies, such as computer-aid training such as Serious Games (SG), Computer-generated Simulations (CGS), VR, AR, and MR, are being introduced to improve construction safety knowledge among workers (Lovreglio et al., 2021; Rahouti et al.,

2021). Burke et al. (2006) state that both passive methods and active methods, such as computer-based instruction and apprenticeship models, have been linked to improved safety and health performance, while more engaging training leads to increased knowledge and reduced accidents. These methods, including VR, are more effective than traditional PowerPoint training methods that can be applied to increase construction safety in Sri Lankan construction industries (Buttussi & Chittaro, 2018). Learning retention rate in literature is based on the Learning Pyramid, which is a model that illustrates the relative effectiveness of different methods of learning. The pyramid shows that VR training is more effective in terms of retaining information compared to other traditional learning methods. Furthermore, some research articles have conducted a comparison of the effectiveness of VR training with traditional training methods (Buttussi & Chittaro, 2021; Sacks et al., 2013).

2.5.1 Virtual Reality Safety Training Applications in Different Industries

Over the past decade, training methods have seen a significant transformation due to virtual reality. For example, according to Cohen et al. (2005), several VR applications have been developed and tested for tsunami and earthquake training (Feng et al., 2021), aviation training (Chittaro, 2012), and counter-terrorism safety training (Buttussi & Chittaro, 2018; Rahouti et al., 2021). As Lucas et al. (2007) point out a computer-generated reality can be a useful option for training tasks that are dangerous in real life. For instance, VR offers a risk-free alternative to traditional surgical training, enhancing students' conceptual understanding of surgical operations and addressing critical training issues in surgeries (Cohen et al., 2005).VR has been utilised in the mining industry since 2014 to prevent accidents and fatalities, providing safety training and exercises for coal mining workers to enhance their understanding of safety protocols (Joshi et al., 2021).VR training allows for the tracking of each behaviour and decision made by users while receiving the training, providing them feedback on what they did correctly (Feng et al., 2021). Here, D'Amico et al. (2023) highlighted a few VR applications focusing on flood safety training such as a VR framework for enhancing disaster awareness. In the case of training and education, Lin et al.(2011) mention that a combination of immersion techniques and SG such as desktop-based VR games can be used to teach university students about safety knowledge in a virtual construction environment.

2.5.2 VR Safety Training in the Construction Industry

There are some research indicates that many applications areas of VR-based training in the construction industry including construction safety (Jeelani et al., 2020), operating construction equipment (Song et al., 2021), construction operation training (Vahdatikhaki et al., 2019) and performing construction activities (Barkokebas et al., 2019; Wolf et al., 2019). Among them, most of the studies have focused on hazard identification and safety training in the construction industry (Ahn et al., 2020; Jeelani et al., 2020). Xu and Zheng (2021) state that VR-based training is adequate and acceptable to construction sites and promotes learning and knowledge retention. Moreover, promoting learning, consequently, and safety behaviour improvements among the workers are some of the advantages of applying VR-based safety training in the construction industry. It has been demonstrated that VR-based training enhances self-efficiency and safety motivation in recognising safety hazards, with observable impacts on safety behaviours in both the short and long term (Nykänen et al., 2020). VR-based safety training was associated with improved safety behaviour among the non-experts rather than experienced field workers,

indicating potential for training incoming construction workers (Yu et al., 2022). This is a significant outcome considering that the construction sector has been attracting young workers to fill the large number of job vacancies on construction sites at current. Further, Bosché et al.(2016) highlighted the use of an immersive virtual system to enable users to assess and experience working at dangerous heights on construction scaffolds, thereby enhancing workers' safety monitoring and high-risk work skills. Certain construction education researchers attribute several benefits to VR training over on-the-job training and traditional classroom education i.e. VR simulations create a risk-free environment where workers can fail without injuring themselves or others (Bosché et al., 2016) and simulations give workers immediate feedback instead of waiting for an individual to comment on their work. Apart from that VR simulations provide a highly effective means of developing technical skills related to construction work without the added stress of potentially injuring workers or confusing environments (Barkokebas et al., 2019). Accordingly, this study provides detailed information on the effectiveness of VR safety training in construction workers, aiming to enhance safety knowledge and awareness of construction activities.

3. RESEARCH METHODOLOGY

This research adopts a quantitative approach to assess the efficiency of VR tools in enhancing safety knowledge and awareness among construction workers. This research focuses on theories behind safety training methods and knowledge enhancement. This study involves conducting VR-based safety training and PowerPoint presentation-based safety training for selected groups. To evaluate the effectiveness of each method, the study measures the retention rate of safety information among the participants. Additionally, it analyses user experience to identify the strengths and weaknesses of each training method, providing a comprehensive understanding of their relative advantages in improving safety training outcomes. For that selected data gathering techniques is an experiment by conducting safety training for both the control group and test group of construction workers. A total of 60 construction workers took part in this experiment in two distinct groups as a sample size in this research experiment. Each group consisted of 30 workers, and they were tested immediately after the safety training. Each group received 20 minutes of training on the same construction safety topic which was “Work at Height”, yet the test group received a conventional lecture supported with PowerPoint slides (Photos, graphics, and text), while the control group received the same instruction in the virtual construction site. The experimental setup includes safety training sessions and subsequent assessments of safety knowledge retention. In the immersive virtual environment, construction workers undergo VR safety training focusing on hazard recognition and activities related to working at heights, utilising Oculus Go or Gear VR platforms. This scenario is chosen due to "working at height" being one of the highest contributors to construction accidents and hazards. Data collection methods encompass a literature review, questionnaires administered after safety training sessions, and unstructured interviews to gather feedback from workers. The same questions were given to both VR and lecture-based safety training workers, and their answers were collected. This test is called a short-term memory test and collects responses via questionnaires, marks were given to workers who correctly gained knowledge from the safety training, each question allocates ten marks for correct answers to assess their safety knowledge. Feedback sessions were conducted using short time interviews about workers' training experience of both traditional and VR training methods to evaluate the efficiency of safety

training tools to assess the knowledge and awareness gained of construction safety. Furthermore, Data analysis entails descriptive analysis methods, including statistical analysis of questionnaire responses, to assess safety knowledge and awareness. This methodology aims to provide comprehensive insights into the effectiveness of VR tools for enhancing safety knowledge and awareness among construction workers, utilising rigorous experimental design and quantitative analysis techniques.

4. RESULTS AND DISCUSSION

This section presents the key research findings related to two areas; (i) outcomes of questionnaire safety test score analysis, and (ii) feedback gained from unstructured interviews with construction employees.

4.1 SCORE ANALYSIS OF SAFETY TRAINING TEST

4.1.1 Results of Data Collection from Construction Workers

The data collection process involved administering a questionnaire immediately after safety training to construction workers who are working in the construction industry. The questionnaire mainly focused on safety knowledge, particularly regarding working at heights which is one of the significant hazards in the construction industry. The safety tests were conducted immediately after training, with 60 construction workers participating, 30 in each control (VR training) and test group (PP training). Training sessions lasted 20 minutes each, conducted in the local language for clarity. All participants in the training were unskilled male workers in the age range of 20 to 55 years.

The result of the questionnaire (refer to Figure 1) showed that there were significant differences between the workers of the two experimental groups after the training. It is clearly shown that the workers of the control group (VR test) have obtained get relatively high level of scores when considering the dispersion of scores obtained for the graft given in Figure 1. The results for the VR training test showed less variation (with a higher mean) compared to the results for the PowerPoint training may have been more consistently effective among the workers, as evidenced by the narrower range marks.

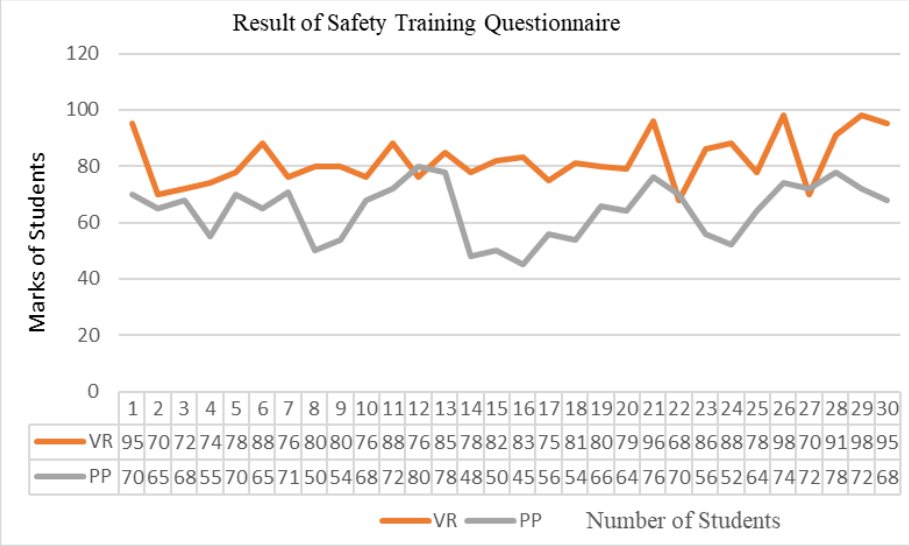

Figure 1: Score variation of safety tests

4.1.2 Descriptive Statistics of Presence Total Mean Score

The average scores of the safety training test obtained from participants of both VR and PP safety training test mentioned that the effectiveness of safety training methods impact to enhances safety knowledge and increases the retention rate of safety information. The following statistical analysis illustrates the effectiveness of safety training methods to enhance the knowledge and memory capacity of the workers.

$$\bar{x} = \frac{\sum x}{n} \qquad (01)$$

Where, $\bar{x}$ = Sample mean, n = No. of participants, $\sum x$ = Total marks of Participant's

The mean result of the VR test = $\frac{(95+72+82+74+\ldots\ldots+95)}{30}$ = **82.13**

The mean result of the PP test = $\frac{(70+65+68+\ldots\ldots+68)}{30}$ = **64.37**

When analysing the results of both safety training methods, it was found that the VR training test had a higher mean score of 82.13%, compared to the PP training test which had an average score of 64.37%. this suggests that a majority of workers who attended the VR training obtained an average mark of about 82%, while those who participated in the PP training obtained an average of 64%. According to the data that were analysed, it seems that VR training is more effective than PP training in improving safety knowledge and awareness among construction workers. The factors that may have contributed to this effectiveness of training methods include engagement, interactivity, immersion, and retention. Therefore, PP training might have been less engaging or memorable for the workers, leading to lower scores overall.

4.1.3 Comparison of Safety Training Methods

When considering the overall marks gained by workers who attended both safety tests, their performance can be categorised into three stages using appropriate benchmarking techniques for assessing and comparing the effectiveness of different training methods by classifying individuals' performance into below benchmarking categories which are shown in Figure 2.

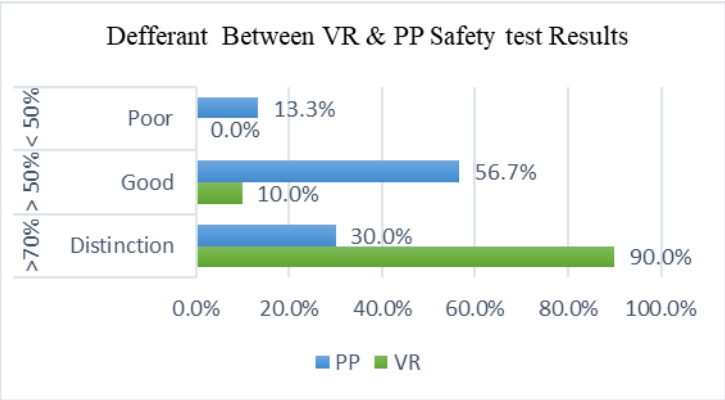

Figure 2: Percentage of result states

Based on the data shown in the figure, VR training is significantly more effective than PP training in achieving high levels of safety knowledge and awareness among workers. Specifically, 90% of workers in VR training achieved a distinction level, compared to

only 30% in PP training. On the other hand, 56.7% of workers in PP training reached a good level, while only 10% achieved the same in VR training. Notably, no workers in VR training fell into the poor performance category, whereas 13.3% of those in PP training did. This indicates that VR training is more efficient in ensuring high proficiency and adherence to safety protocols. It states that workers who participated in VR safety training have maintained higher memory capacity and higher-level retention rates comparing PP Safety Training programmes. Factors such as Quality of instructions, engagement and interaction can impact this higher percentage of score level with the "Distinction category" created from VR safety training compared to PP safety training. Accordingly, this analysis demonstrates how VR training may be more effective than PowerPoint training in increasing construction worker safety knowledge and awareness. This analysis demonstrates how VR training may be more effective than PowerPoint training in increasing construction worker safety knowledge and awareness.

After analysis of the experiment data which were gathered from all participants, it was found that there was a significant impact on the scored differences among both training methods by the Age of the workers. Table 2 clearly shows these knowledge differences based on the worker's average score on the safety test.

Table 2: Average results in different age groups

Age group	VR Av. Score (%)	PP Av. Score (%)
Below 21	79	0
21 - 30	86.57	76.4
31 - 40	81.18	67.23
41 - 50	70	55.56
Above 50	0	58.33

Age-related discrepancies could be impacted by different memory capacities and familiarity with technologies. This impact difference indicates the above table comparison which is the average scores that workers obtain from their safety test in different age groups. When analysing average score levels in different age groups in VR and PP safety training methods, the immersive quality of VR training may positively affect to increased knowledge of younger workers. Moreover, both safety training test scores gradually decreased with the increasing age of the workers. Therefore, while age-related factors can influence safety knowledge scores, the design and implementation of training programmes must consider memory capacity and familiarity with technology into account to ensure that they are effective for different age groups. Accordingly, highly engaging safety training methods such as VR safety training contribute to maintaining higher capacity safety knowledge for both younger and older workers.

4.2 FEEDBACK DISCUSSION

User experience is another factor that can measure the effectiveness of the safety training methods. The level of engagement with the training material and methods can significantly impact workers' understanding and retention of the safety knowledge. In this research, the target population consisted of unskilled construction workers with low levels of education (all participants had completed up to ordinary level or advanced level). Therefore, unstructured interviews in the form of discussions with participants were conducted to gather participants' feedback on their user experiences with each safety training method. As per the feedback of the participants, it can be identified that highly

engaging safety training methods such as Virtual Reality safety training methods are more effective than traditional training methods for enhancing safety knowledge and safety performance among construction workers. Furthermore, they highlighted that conducting safety training by using VR technology is practical for providing a clear understanding of the seriousness of the risks and giving real experiences about construction accidents and hazards within a safe environment rather than conducting lecture-based PP safety training. Analysing the feedback given by the construction workers who attended VR safety training, found that this is the first time they participated in a VR safety training program, and they preferred to actively participate in this kind of engaging safety training rather than PowerPoint training.

4.3 LIMITATIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

This study encountered several limitations that should be addressed in future research. One of the main limitations is that the VR training scenario was in the English language, which may not be familiar to the construction workers. Developing localized VR training modules in local languages will ensure that all trainees can fully understand and benefit from the training materials. Another one is that the data collection was limited to a one-time safety test due to time constraints, which hindered the ability to accurately measure the long-term retention of safety knowledge. For that, implementing long-term investigations that include safety tests conducted before the training, immediately after, and one-month post-training will provide a more accurate measurement of both short-term and long-term retention of safety knowledge. The study was also restricted to a single safety scenario, due to a lack of diverse and freely available VR safety training programs in Sri Lanka. However, expanding the VR training content to cover a variety of safety scenarios will offer a more comprehensive safety training program. Furthermore, the limited availability and high cost of suitable VR tools posed significant challenges, affecting the feasibility and scalability of VR safety training. However, developing or investing in affordable and locally available VR tools will support wider adoption and more effective implementation of VR safety training programs in the construction industry.

5. CONCLUSIONS

This study was conducted to assess the effectiveness of VR tools to enhance the safety knowledge and awareness of construction workers. The aim of this research is to evaluate the efficiency of VR tools to enhance the safety knowledge and awareness of construction workers. The research findings demonstrate the potential of VR technology as an innovative and engaging tool for improving safety training outcomes among construction workers in Sri Lanka. Further study's finding highlighting VR safety training can significantly enhance safety knowledge and awareness, as evidenced by the higher scores obtained by workers in the VR test group compared to the control group that received PP-based training. Moreover, feedback from construction workers who participated in VR safety training indicates a preference for this interactive and immersive training approach (VR) over traditional methods. The study identifies the need for future research to address limitations such as language barriers and the frequency of safety test assessments to further enhance the effectiveness of VR safety training programs. In conclusion, the research underscores the importance of leveraging technological advancements such as VR tools to revolutionise safety training in the construction industry. By embracing

innovative training methods that actively involve workers and simulate real-world scenarios, construction companies in Sri Lanka can enhance safety practices, reduce worksite accidents, and ultimately create a safer working environment for all employees.

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