ORIGINAL ARTICLE

Evaluating the effectiveness of a virtual reality-based training method for basic scuba diving skills

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Abstract

Background and Study Aim: Traditional scuba diving training often faces challenges in creating a safe and effective environment for beginners. Virtual reality (VR) technology offers a more interactive simulation to improve basic diving skills before participants dive into the real environment. This study aims to analyze the effectiveness of VR-based training methods compared to traditional training methods in improving basic diving skills in beginners.

Material and Methods: This study used a two-group pretest-posttest experimental design, with 64 university students (aged 17-19 years) randomly divided into an experimental group (n = 32) and a control group (n = 32). The experimental group attended scuba diving training using VR, while the control group received traditional training involving classroom sessions and pool exercises. For 12 weeks, the experimental group also received 60 minutes of scuba diving training once a week. Diving skills were measured before and after the intervention using a basic diving skills test. Data analysis was aided using SPSS 26.

Results: The Wilcoxon test results showed that there was a significant effect between the pretest and posttest in both groups ($p = 0.000$), which means that both the control group and the experimental group had improved diving skills after the intervention. The posttest results showed that the experimental group had a significant improvement in diving skills (mean = 95) compared to the control group (mean = 75) with $p < 0.05$. Mann-Whitney U analysis showed a significant difference between the two groups ($Z = -6.756$, $p < 0.05$), indicating that the VR method was more effective than the traditional method.

Conclusions: VR-based training was shown to be more effective in improving basic diving skills than traditional methods. The use of this technology can be an innovative alternative in scuba diving training programs for beginners.

Keywords: virtual reality, scuba diving, diving training, basic skills, learning technology

Introduction

Scuba diving is an activity that requires complex technical skills, including buoyancy control, breathing coordination, and adaptation to the underwater environment. Conventional training for divers usually involves practical sessions in swimming pools or open water with experienced instructors [1]. However, traditional training methods have limitations, such as limited accessibility, high costs, and safety risks for novice divers [2]. In addition, unfavorable environmental conditions, such as bad weather or low visibility, can also hinder the training process [3]. Therefore, technology-based training methods, such as virtual reality, have been developed as a more effective alternative to improving basic diving skills.

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Virtual reality technology allows for the simulation of underwater environments that closely resemble real conditions. It is already utilized across multiple sectors, including education, training, sports, and healthcare [4]. Virtual reality has been used in various fields of sports and physical rehabilitation to improve individuals' motor and cognitive skills [5]. In the context of scuba diving training, virtual reality can help novice divers understand basic concepts, such as buoyancy control and breathing management. It even helps with underwater navigation without the risks inherent in live training in open water [6].

The main problems in scuba diving training are the risk of accidents due to lack of experience, inability to manage underwater stress, and lack of understanding of effective breathing techniques [7]. In addition, the instructor's limitation in supervising each individual during training in a real environment is a factor that

can affect the effectiveness of learning. Therefore, the development of virtual reality-based training methods is a potential solution to overcome these obstacles. Virtual reality not only provides an opportunity for divers to practice independently and repeatedly without risk, but also allows for the use of data analysis to evaluate their skill development [8, 9, 10].

Several studies have demonstrated the effectiveness of virtual reality in water sports training. For example, in studies on diver training, virtual reality was shown to significantly improve conceptual understanding and motor skills compared to traditional methods [2, 11, 12]. In addition, the application of virtual reality in training swimmers has also been shown to help optimize movement patterns, as well as improve spatial awareness and body coordination [3]. Thus, the integration of virtual reality in scuba diving training is expected to provide similar benefits, especially in improving basic skills for novice divers.

The novelty of this study lies in the empirical evaluation of the effectiveness of virtual reality in improving basic scuba diving skills compared to traditional methods. This study not only explores the advantages of virtual reality technology in training [13, 14], but also highlights the challenges of its implementation, including technical, economic, and psychological factors that may affect learning success. Therefore, this research has high significance in providing new insights for the development of safer, more efficient, and accessible scuba diving training methods.

Furthermore, this study also sought to identify key factors that influence success, especially in learning in virtual reality-based scuba diving training, including cognitive aspects, motor skills, and participants' risk perception [4]. In addition, this research is expected to contribute to the development of a more adaptive and technology-based training curriculum, aimed at increasing the accessibility and effectiveness of training for prospective divers from various backgrounds.

Nevertheless, there are still some challenges in the application of virtual reality for scuba diving training, such as technological limitations in simulating the real physical effects of diving, the need for sophisticated hardware, and relatively high development costs [15, 16]. Therefore, this study aims to evaluate the effectiveness of virtual reality-based training methods in improving basic scuba diving skills and compare them with conventional training methods, as well as identify solutions to improve the wider application of virtual reality in scuba diving training.

Materials and Methods

Participants

This study used a random sampling technique to determine the distribution of the control group (CG) and the experimental group (EG). Each participant from a population of 64 students (aged 17–19 years) had an equal chance of being included in one of the two groups.

The randomization process was conducted using a software-assisted simple random sampling method or the lottery method, so that the distribution of participants in the two groups was not influenced by any subjective factors. Using this method, 32 students were randomly placed in the control group (CG), which underwent conventional scuba diving training, while the other 32 students were placed in the experimental group (EG), which underwent virtual reality-based training. This approach ensures that the initial characteristics of the participants in both groups are balanced, so that differences in the results obtained can be more accurately attributed to the treatment provided rather than to other uncontrolled factors.

Table 1. Research Population

No.	Group	Total
1	Experimental Group (EG)	32 Students
2	Control Group (CG)	32 Students

Research Design

This research is a quantitative study with an experimental study approach [17]. This research design used a two-group pretest and posttest design, namely an experimental group that received virtual reality-based training and a control group that received traditional training. Each group consisted of 32 participants randomly selected from a population of novice divers. The population and sample of this study were adult individuals who had never attended scuba diving training before. The sample was randomly drawn and divided into two groups (virtual reality group and traditional group), with 32 participants each.

Research Procedure

The experimental group (EG) underwent scuba diving training using a virtual reality (VR) system powered by the Blu software, which provided an immersive underwater simulation experience. The VR training incorporated motion-tracked hand controllers to simulate equipment handling, real-time breathing feedback, and interactive underwater navigation scenarios. Each session lasted 60 minutes, conducted twice per week for 12 weeks, following a structured progression from basic breathing exercises to advanced underwater orientation and emergency response drills. Meanwhile, the control group (CG) participated in traditional scuba diving training, which included theoretical classroom sessions covering diving safety, equipment handling, and breathing techniques, followed by practical pool exercises. The training schedule was designed

to match the VR group's exposure, with 60-minute sessions held twice a week over 12 weeks.

After completing the training, both groups were assessed using the CMAS One-Star Diver Standard, which evaluates key scuba diving skills, including breathing techniques, equipment handling, and underwater orientation. Breathing skills were assessed based on participants' ability to use the scuba regulator properly, regulate breathing, and manage underwater stress. Equipment handling evaluation focused on the correct handling and adjustment of diving gear, such as mask clearing, regulator recovery, and buoyancy control. Underwater orientation assessment measured participants› navigation skills, spatial awareness, and ability to maintain neutral buoyancy while following a designated dive path. The assessment was conducted by certified CMAS diving instructors, who used a standardized scoring rubric to evaluate participants› accuracy, efficiency, and confidence in performing each skill.

Additionally, a questionnaire was administered to collect participants' perceptions of their learning experience, engagement, and confidence levels post-training [18]. To further enhance participants' comfort in aquatic environments, both groups also took part in scuba diving training once a week for 60 minutes over 12 weeks, which included basic water adaptation exercises to improve familiarity and ease in underwater settings.

Statistical Analysis

After the data from the sample were collected, they were analyzed using descriptive statistical analysis techniques. In descriptive statistical analysis, the goal is to find the highest value, lowest value, average, median, and mode, as well as standard deviation. Before testing the research hypothesis, it is necessary to conduct a preliminary test. The results of this testing aim to improve the accuracy of the analysis. For this reason, a data normality test was conducted in this study.

Before moving on to the t-test, a key assumption must be met: the analyzed data must be normally distributed. If not, a non-parametric test will be used. This analysis was assisted by SPSS version 26 software.

Results

Based on the analysis results in Table 2, the characteristics of the study participants, including age, height, weight, BMI, and the number of male and female participants, showed no significant differences between the control group (CG) and the experimental group (EG). This indicates that both groups had comparable baseline characteristics before the intervention.

The descriptive results of diving skills in Table 3 show that before the intervention, the average pretest scores of the control group (75.12) and the experimental group (75.37) were almost the same. However, after the intervention, the experimental group showed a significant increase, with an average posttest score of 94.56, compared to the control

Table 2. Characteristics of participants

Variables	CG	EG	p value
N	32	32	
Male	19	18	
Female	13	14	
Age (years)	18.55±0.09	18.45±0.09	NS
Height (m)	1.65±0.06	1.69±0.07	NS
Weight (kg)	65.04±6.43	60.58±6.69	NS
BMI (kg/m2)	16.28±	16.98±3.73	NS

Notes: CG : Control Group; EG: Experimental Group; BMI: Body Mass Index

Table 3. Descriptive Results of Diving Ability

Results	Group	N	Mean	Std. Deviation	Std. Error	Minimum	Maximum
Pretest	Control Group	32	75.1250	4.05407	0.71667	60.00	82.00
	Experimental Group	32	75.3750	3.48962	0.61688	65.00	82.00
	Total	64	75.2500	3.75436	0.46930	60.00	82.00
Posttest	Control Group	32	78.8438	3.08073	0.54460	70.00	85.00
	Experimental Group	32	94.5625	4.21164	0.74452	80.00	100.00
	Total	64	86.7031	8.72631	1.09079	70.00	100.00

group, which only reached 78.84. This indicates a greater improvement in the experimental group after the treatment.

The results of the Shapiro-Wilk normality test showed that most of the data were not normally distributed, except for the control group posttest (p = 0.091), which met the assumption of normality. The control group pretest (p = 0.000), the experimental group pretest (p = 0.004), and the experimental group posttest (p = 0.000) all showed an abnormal distribution (p < 0.05). Since the data were not completely normal, further analysis was conducted using non-parametric tests, namely the Wilcoxon Signed-Rank Test to measure the improvement within each group and the Mann-Whitney U Test to compare the posttest results between the control and experimental groups.

Non-parametric tests were chosen because they are more suitable for data with non-normal distributions, ensuring that the results of the analysis remain valid and accurate. The results can be seen in Table 4.

The Wilcoxon test results presented in Table 5 indicate a significant difference between pretest and posttest scores in both groups (p = 0.000), suggesting that participants in both the control and experimental groups experienced an improvement in their diving skills following the intervention. However, the increase in diving ability was more pronounced in the experimental group than in the control group.

In this study, the Wilcoxon Signed-Rank Test was applied to compare pretest and posttest results in both groups. In addition to analyzing the Z value and significance level (Sig.), an effect size (r) was calculated to determine the magnitude of improvement in diving skills. The effect size was computed using the formula $r = Z/\sqrt{N}$, where Z represents the Wilcoxon statistical value, and N is the total number of participants in the study. The findings revealed that the Z value was -4.977 for the control group and -4.944 for the experimental group, with each group consisting of 32 participants. Based on this formula, the calculated effect size was r = 0.88 for the control group and r = 0.87 for the experimental group.

According to standard interpretations, an effect size of $r \geqslant 0.5$ is considered large, indicating that both conventional and virtual reality-based training had a substantial impact on enhancing participants› diving skills. While both groups showed significant improvement, further analysis is necessary to determine whether virtual reality-based training offers additional benefits over conventional methods in specific areas, such as learning effectiveness, skill retention, and participants'confidence levels.

Furthermore, the Mann-Whitney U test in Table 6 shows that there was a significant difference between the posttest results of the two groups (p = 0.000), with the experimental group showing a higher improvement than the control group. The Z value of -6.756 indicates a significant difference between the two groups, with the experimental group showing greater improvement in diving skills than the control group. This analysis demonstrates that the virtual reality- and water game-based training method applied to the experimental group was significantly more effective than the traditional training method in improving novice diving skills.

Table 4. Shapiro Wilk Normality Test Results

Result	Statistic	df	Sig.
Pretest Control	0.839	32	0.000
Posttest Control	0.943	32	0.091
Experiment Pretest	0.894	32	0.004
Experiment Posttest	0.832	32	0.000

Table 5. Effect Test Results of Control Group and Experimental Group

Results	Indicator	Analysis	Z	Sig. (2- tailed)	Description
Pair 1	Control Group Pretest and Posttest	Wilcoxon	-4.977[c]	0.000	Significant
Pair 2	Experimental Group Pretest and Posttest	Wilcoxon	-4.944[c]	0.000	Significant

Table 6. Mann-Whitney U test results

Results	Posttest
Mann-Whitney U	10.500
Wilcoxon W	538.500
Z	-6.756
Asymp. Sig. (2-tailed)	.000

a. Grouping Variable: Group

The superiority of this method can be attributed to the more realistic simulation and a more interactive learning environment, which enable participants to better understand breathing techniques, equipment usage, and underwater orientation before actually diving into the real environment.

Discussion

The results showed that the virtual reality (VR)-based training method was significantly more effective in improving basic scuba diving skills than the conventional training method. From the skill test results, the experimental group (EG) using virtual reality showed greater skill improvement than the control group (CG). The mean score of the EG's diving skill test was 94, while the CG's only reached 75 ($p < 0.05$). This finding indicates that virtual reality can provide a more effective training environment for building conceptual understanding and motor skills in novice divers.

From the results of the parametric analysis, no significant differences were found in the participants› baseline characteristics, such as age, height, weight, and body mass index (BMI), between the control and experimental groups. This suggests that the improvement in diving skills observed in the group using virtual reality was not due to individual characteristics, but rather to the effectiveness of the training method applied.

In addition to improved technical skills, most participants in the experimental group reported a more engaging and interactive learning experience. They stated that the use of virtual reality helped them feel more prepared and confident before attempting real-world dives [2,19]. In contrast, the control group that followed conventional training tended to experience boredom and increased anxiety when dealing directly with an open water environment. This aligns with previous research showing that virtual reality can reduce anxiety levels and increase learning motivation in challenging training contexts [5].

The main advantage of virtual reality in scuba diving training is its ability to create a safe, realistic, and repeatable training environment without physical risk [20]. The delivery of information in the form of interactive simulations allows participants to hone their skills unencumbered by external factors such as weather conditions or limited training facilities. Furthermore, the effectiveness of virtual reality-based training can also be attributed to the experiential nature of learning, which allows participants to learn from their mistakes in a controlled environment before transitioning to real waters [21,22].

However, there are several challenges in applying virtual reality to scuba diving training. One of these is the limitation of simulating the real physical effects of diving, such as water pressure, temperature, and motion resistance. Additionally, the absence of haptic feedback further reduces the realism of training, as participants cannot experience the tactile sensations of handling equipment underwater or the physical resistance of movement. This limitation may affect skill transfer when transitioning to real-world diving conditions.

In addition, investment in virtual reality devices and the development of appropriate software remain major obstacles to the widespread adoption of this technology [2]. High costs associated with VR hardware, software development, and maintenance make it less accessible, particularly for smaller training centers or individual learners.

Despite these limitations, strategic measures are needed to improve the accessibility and effectiveness of virtual reality for scuba diving training. Further research should explore ways to integrate haptic technology to enhance sensory engagement and improve skill acquisition. Moreover, the development of more cost-effective and scalable VR training programs is crucial to increasing adoption and making this technology more feasible for a wider range of users.

Overall, this study demonstrates that virtual reality-based training has great potential for improving basic scuba diving skills, both in terms of technical effectiveness and psychological aspects such as participants' confidence and motivation. However, a more critical analysis is required to address the current limitations of VR training and explore solutions that can enhance its realism, affordability, and effectiveness. With the continuous development of virtual reality technology, there will be more opportunities to optimize this training method, which in turn can provide innovative solutions for the scuba diving training industry in the future.

Conclusions

Based on the results of the analysis, it can be concluded that the intervention provided to the experimental group with virtual reality significantly improved diving skills compared to the control group. Although both groups improved, the higher results in the virtual reality group suggest that virtual reality-based training combined with water games is more effective for improving basic diving skills than traditional training methods. In addition, the learning experience using virtual reality was more engaging and reduced participants› anxiety. Therefore, this technology-based training can be a valuable and innovative alternative to diving instruction programs for beginners.

Further research should explore the use of virtual reality in more complex diving skills training, such as deep-sea navigation and underwater crisis management. In addition, the development of more specific and realistic virtual reality devices

for scuba diving training could further increase the effectiveness of this training.

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Conflict of Interest

The authors report that there are no competing interests to declare.

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