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Original Article

The Effect of a Virtual Reality-Based Physical Education Program on Physical Fitness among Elementary School Students

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Abstract

Background: This study aimed to verify the effectiveness of a virtual reality-based physical education program on physical fitness among Korean elementary school students.

Methods: The study, conducted at a public school in South Korea in the second semester of 2022, included experimental and control groups of 45 participants each (N=90). All participants underwent physical fitness tests before and after the experiment. The students assigned to the experimental group participated in the virtual reality-based physical education program three times a week for a total of 8 weeks (40 minutes per session), while those assigned to the control group did not participate in any exercise program. The effect size was confirmed using Cohen's d, and a two-way repeated measures analysis of variance was used to analyze changes in physical factors before and after the experiment for each group.

Results: Among the male participants, we observed significant differences in overall health-related physical fitness, cardiorespiratory endurance, muscular strength and endurance, and power between the experimental and control groups ($P<0.05$). Among the female participants, we observed significant differences in overall health-related physical fitness, cardiorespiratory endurance, flexibility, and muscular strength and endurance between the groups ($P<0.05$).

Conclusion: Virtual reality-based physical education may help to improve indicators of physical fitness among elementary school students, especially among those who have experienced deterioration of physical fitness during the COVID-19 pandemic. Our results, therefore, highlight the need to establish virtual reality-based physical education facilities at the elementary school level in Korea.

Keywords: Elementary school; Physical activity; Physical education; Physical fitness; Virtual reality

Introduction

The prolonged COVID-19 pandemic has exerted a significant impact on physical activity levels among children, decreasing levels of moderate- and high-intensity physical activity by approximately 30 minutes on weekdays and 15 minutes on weekends compared to pre-pandemic activity levels (1). 78.1% of children failed to maintain usual physical activity habits during the COVID-19 outbreak (2), highlighting the additional burden associated with sedentary behavior in the context of the pandemic and its potential adverse effects on health (3-4). Based on these reports (1-

4), researchers have expressed growing concern regarding the impact of obesity and metabolic alterations in young people during the COVID-19 pandemic.

Both adults and children categorized as overweight are more likely to be exposed to cardiovascular risk factors such as hyperlipidemia, hypertension, and diabetes (5), which can lead to adverse effects on both physical and mental health (6). Furthermore, children who are overweight are more likely to be overweight or obese in adulthood in the absence of intervention (7). Ultimately, these findings emphasize that children who have been unable to engage in physical activity during the COVID-19 pandemic face extreme barriers in returning to baseline activity levels. This, in turn, may increase their risk of developing obesity, metabolic syndrome, and mental health disturbances in adulthood.

Decades of research have emphasized that physical education at the elementary school level exerts a significant impact on low levels of physical activity. Physical education provides opportunities for children to be active during their formative years despite differences in socioeconomic status and regions where children reside. Indeed, a recent systematic review and meta-analysis (8) has documented the value of physical education for promoting physical fitness components and fundamental movement skills (FMS). These findings highlight physical education as an excellent starting point for addressing the lack of physical activity during the COVID-19 pandemic and the various problems that may be associated with such changes.

Recently, physical activity programs incorporating virtual reality (VR) have been gaining popularity in Korea. Such programs allow students to actively engage in physical activity by kicking or throwing a ball toward a target on a large screen or by imitating specific movements. For example, motion recognition cameras can recognize ball trajectory and body movement, allowing participants to visually implement desired movements on the screen (9). Given such findings, the Korean Ministry of Culture, Sports, and Tourism initiated a virtual reality sports room technology development project in 2015, distributed to elementary schools for the first time in 2016. The demand for such instruction has increased each year, from 10 in 2017 to 130 in 2018 and 112 in 2019. Given these trends, the project is expected to reach 10% of all elementary schools by 2023 (10).

Virtual reality environments permit students to access heretofore inaccessible programs via dedicated software, which in turn allows researchers to examine relationships between physical activity and environmental constraints within a school setting (11). As a simple example, virtual World Cup free-kick soccer simulations allow students to compete and engage in meaningful activities with their peers. This prompts students to actively participate in physical fitness-related programming (12). In more advanced settings, the speed, direction, and distance of the ball can be calculated to provide immediate and accurate feedback to student athletes (13). These advantages can help improve educational outcomes such as communication skills and self-efficacy (14).

Physical activity in the schools is the basis for lifelong sports (15). Moreover, regular physical activity in adulthood is significantly related to quality of life such as well-being (16). Therefore, physical education provided in schools is very important.

To identify strategies that may be effective in promoting physical activity among elementary school students who have lived through the COVID-19 pandemic, the study developed a virtual reality-based physical activity program for distribution at the national level. The current findings, when taken with those of previous reports, highlight the educational effectiveness of Edu-Tech in the context of physical fitness education (17).

Materials and Methods

Participants

The present study, conducted in the second semester of 2022, included students attending a public elementary school in Korea. The school was established in 2019 and is equipped with various state-of-the-art facilities. A total of 1,101 students (556 boys and 535 girls) were enrolled at the school at the time of the study. Among these, 122 students (63 boys and 59 girls) in 5th grade and 137 students (69 boys and 68 girls) in 6th grade were potential study participants.

Prior to recruitment, we obtained approval and consent from the physical education teacher at the school. The study protocol was reviewed and approved by the Ethics Committee of the Korea National University of Education (approval number: IRB 202036308) and conformed to the standards set by the latest revision of the Declaration of Helsinki. All participants for whom data are reported provided written consent.

Next, a guide for recruiting potential study participants, including information on the program, was prepared and sent to the families of 5th and 6th grade students. Finally, 90 students who expressed their intention to participate were selected for inclusion. All students and parents expressing interest were provided with a detailed explanation regarding the study's purpose, content, and procedures.

Prior to implementation of the virtual reality-based program, all 90 participants underwent baseline physical fitness testing. Thereafter, participants were divided into an experimental and control group. The experimental group participated in the virtual reality-based physical education program, while the control group did not participate in any physical activity program. A post-physical fitness test was conducted after completion of the program.

Table 1 presents the characteristics of the participants. Under the assumption that there would be differences in the change patterns according to program participation due to the developmental characteristics of boys and girls, the participants were divided according to gender. Following this, analyses were conducted for the experimental and control groups. An independent t-test using age, height, weight, and body fat percentage as variables revealed no significant difference between the groups (all *P*s > 0.05). Therefore, when analyzing the experimental results, covariate adjustments were not made based on the characteristics of the participants.

Table 1: Characteristics of the participants

Variable	***Total (N=90)***	***Boys (n=42)***			***Girls (n=48)***		
		EG (n=19)	CG (n=23)	t/*P*	EG (n=26)	CG (n=22)	t/*P*
Age (yr)	10.77±0.64	10.75±0.68	10.72±0.61	0.163/0.871	10.76±0.59	10.87±0.69	0.587/0.560
Height (cm)	149.38±7.53	150.68±6.84	148.02±8.34	1.216/0.230	149.64±7.81	149.23±7.19	0.188/0.851
Weight (kg)	46.77±10.73	48.96±11.37	45.56±11.68	1.032/0.308	47.14±9.41	45.39±10.63	0.606/0.548
Body fat (%)	27.34±8.14	25.83±8.46	27.22±8.19	1.055/0.297	29.64±7.49	26.61±8.39	1.325/0.192

EG: experimental group, CG: control group; tested via independent *t*-test

Virtual reality-based physical education program

The virtual reality-based physical education program was conducted in a separate facility at the school in which the participants were enrolled. Large screens were installed on both walls of this space, and laser sensors were located around the screen to detect collisions of objects or human bodies. A motion tracking sensor was installed on the ceiling to calculate the trajectory, speed, and distance of relevant objects (i.e., balls). The program was controlled using a dedicated kiosk connected to a computer. Programs were presented on a large screen using a ceiling beam projector, allowing for various types of visual content to be presented based on learners' interests. The content included stretching, reciprocating running, hitting objects using a ball, and various sports-related activities (e.g., football free kick, baseball batting and pitching, archery, and bowling). A cycle ergometer was connected to a computer on the other wall of the dedicated space. Students were permitted to move through various maps during the cycle exercises while monitoring mileage, height, rank, time, and other parameters in conjunction with the study participants. In this space, an Xbox360 device (Microsoft Corporation, Redmond, WA, USA) equipped with Kinect was installed for motion recognition. Students were provided the opportunity to engage in skiing, boxing, and dancing games (among activities) (Fig. 1).

Fig. 1: Virtual reality-based physical education program facilities

Students participated in the virtual reality-based physical education program for a total of 8 weeks, from September to October 2022. Participants in the experimental group attended three times per week for a total of 24 times, with each activity lasting 40 minutes (Table 2). The first and last 5 minutes of each session were dedicated to warm-up and clean-up exercises, including gymnastics and stretching exercises. The physical education teacher observed and gave feedback during the warm-up exercise and guided participants to gradually expand their range of motion to improve flexibility and stability. The 30 minutes between the warm-up and cool-down exercises were divided into segments of 10 minutes each, during which other activities were performed. The first segment included round-trip running to improve cardiorespiratory endurance. Running sessions started from the opposite wall, approximately 30 meters away from the screen, and participants were required to touch a virtual point on the screen, check the number of repetitions, and return to the starting point. At this time, the physical education teacher adjusted the number of repetitions and the distance to achieve the exercise program's desired effect. In the second phase, participants engaged in a ball-throwing activity designed to improve upper body strength and muscular endurance. Participants were required to throw balls of various sizes and weights toward fixed and moving targets. Archery and baseball activities were performed in parallel. For this activity, the physical education teacher prepared many balls in advance so the throwing action could be repeated within a short period, allowing participants to compete and attempt to beat their personal records. In the third segment, participants completed a ball-kick activity to improve lower body strength and muscular endurance. In this session, participants were instructed to hit the target by repeatedly kicking the ball in penalty-kick, free-kick, and long-kick soccer environments. During this session, the physical education teacher increased the number of balls for each participant to ensure a steady, repetitive movement similar to the throwing activity. Participants were divided into several groups based on their engagement in sports, cycling, and Xbox360 activities (Microsoft Corporation, Redmond, WA, USA).

Table 2: Virtual reality-based physical education program process

Process	*Time*	*Target factor*	*Activity type*	*Activity example*
Warm-up and cool-down exercises	10 min	Flexibility and stability	Gymnastics and stretching exercise	
Whole body activity	10 min	Cardiorespiratory endurance	Round-trip running, cycling, and Xbox360 activities	
Upper body activity	10 min	Upper body strength and muscular endurance	Ball-throwing	
Lower body activity	10 min	Lower body strength and muscular endurance	Ball-kicking	

Physical fitness test

Cardiorespiratory endurance, muscular strength and endurance, flexibility, power, and body mass index (BMI) were measured before and after each session for both experimental and control groups. The overall health-related physical fitness score was based on five calculated areas (18). Cardiorespiratory endurance was measured through a 15-meter shuttle-run test. Participants start with a signal from the starting point and must move to the next position before the next beep sounds. If the participant fails to reach the position before the beep sounds, the measurement ends. Muscular strength and endurance were measured using a sit-up test, in which participants began lying down with their knees bent at 90° with both hands placed on their thighs. Every 3 seconds the participants were instructed to roll their upper body in accordance with the beep, and the number of times both hands touched the hand of the person holding the operator's knee was measured. Flexibility was measured using the sit-and-reach test. In this test, participants placed their feet in contact with the vertical plane of the measuring instrument, sat with their legs extended, bent their upper body completely over with the start signal from the measuring instrument, and overlapped the palms of both hands. Power was determined based on a 50-meter dash. BMI was calculated using the participant's height and weight (19).

Statistical analysis

The data are presented as means and standard deviations, and independent *t*-tests were used to verify differences between the experimental and control groups according to gender. Paired *t*-tests were conducted to verify the statistical significance of differences between the experimental and control groups before and after the experiment, and the effect size was confirmed using Cohen's d. In addition, a two-way repeated measures analysis of variance was conducted to examine changes in physical fitness factors before and after the experiment, and the effect size was based on the partial eta squared (η2p) value. Statistical analysis was performed using SPSS version 24.0 (IBM Corp., Armonk, NY, USA), and the significance level was set at $P<0.05$.

Results

Tables 3 and 4 show changes in physical fitness factors for the male and female groups, and experimental and control groups. Among the male participants in the experimental group, we observed statistically significant changes in overall health-related physical fitness scores ($P<0.001$), flexibility ($P=0.003$), muscular strength and endurance ($P=0.002$), power ($P=0.010$), and BMI ($P=0.041$). No difference was observed in cardiorespiratory endurance ($P=0.068$). Among the female participants in the experimental group, we also observed statistically significant changes in overall health-related physical fitness scores ($P<0.001$), flexibility ($P<0.001$), muscular strength and endurance ($P<0.001$), power ($P<0.001$), and BMI ($P=0.032$). As was the case with the boys, there was no significant change in cardiorespiratory endurance ($P=0.187$). Within the control group, male participants exhibited no statistically significant changes in any factor other than cardiorespiratory endurance ($P=0.029$). Female participants in the control group also exhibited no statistically significant differences in any factors other than cardiorespiratory endurance ($P=0.013$).

Table 3: Changes in physical fitness factors among male students

Fitness factor	*Group*	*Pre*	*Post*	*t*	*P*	*Cohen's d*	*Source*	*F*	*P*	*η^2p*
Overall health-related physical fitness scores	EG (n=19)	26.42±6.35	43.89±12.22	7.101	<0.001***	1.846	Time	50.570	<0.001***	0.558
	CG (n=23)	28.35±6.23	29.00±7.99	0.583	0.566	0.127	Time×Group	43.553	<0.001***	0.521
Cardiorespiratory endurance	EG (n=19)	8.53±6.24	11.32±4.47	1.940	0.068	0.458	Time	0.380	0.541	0.009
	CG (n=23)	9.57±4.28	7.74±3.32	2.336	0.029*	0.501	Time×Group	8.723	0.005**	0.179
Flexibility	EG (n=19)	2.42±3.45	5.53±3.70	3.385	0.003**	0.779	Time	8.869*	0.005**	0.181
	CG (n=23)	4.52±5.45	5.13±4.80	0.722	0.478	0.153	Time×Group	4.008	0.052	0.091
Muscular strength and endurance	EG (n=19)	7.53±4.50	13.05±4.17	3.681	0.002**	0.844	Time	19.147	<0.001***	0.324
	CG (n=23)	7.17±4.65	8.65±4.22	1.934	0.066	0.406	Time×Group	6.395	0.015*	0.138
Power	EG (n=19)	4.00±3.38	7.00±2.85	3.983	0.010**	0.927	Time	17.005	<0.001***	0.298
	CG (n=23)	3.91±3.79	4.30±3.77	0.941	0.357	0.196	Time×Group	10.062	0.003**	0.298
Body mass index	EG (n=19)	3.79±2.82	5.47±3.12	2.202	0.041*	0.505	Time	7.675	0.008**	0.161
	CG (n=23)	5.22±4.51	5.61±4.15	1.521	0.142	0.331	Time×Group	2.978	0.092	0.069

EG: experimental group, CG: control group.
*$P<0.05$, **$P<0.01$, ***$P<0.001$; tested via paired t-test and two-way repeated-measures analysis of variance

Table 4: Changes in physical fitness factors among female students

Fitness factor	*Group*	*Pre*	*Post*	*t*	*P*	*Cohen's d*	*Source*	*F*	*P*	*η²p*
Overall health-related physical fitness scores	EG (n=26)	28.77±6.06	47.54±7.62	9.218	<0.001***	2.096	Time	75.117	<0.001***	0.620
	CG (n=22)	33.50±5.32	35.00±5.34	1.851	0.078	0.394	Time×Group	54.527	<0.001***	0.542
Cardiorespiratory endurance	EG (n=26)	9.27±5.98	11.08±4.04	1.358	0.187	0.273	Time	0.014	0.905	0.000
	CG (n=22)	11.77±5.06	9.77±4.78	2.730	0.013*	0.584	Time×Group	5.677	0.021*	0.110
Flexibility	EG (n=26)	3.73±3.83	8.85±5.36	4.899	<0.001***	0.990	Time	21.104	<0.001***	0.315
	CG (n=22)	3.73±4.75	4.50±5.56	1.199	0.244	0.264	Time×Group	11.480	0.001**	0.200
Muscular strength and endurance	EG (n=26)	6.00±3.31	12.38±4.92	5.157	<0.001***	1.183	Time	26.643	<0.001***	0.367
	CG (n=22)	7.00±2.91	9.09±4.41	2.047	0.053	0.450	Time×Group	6.838	0.012*	0.129
Power	EG (n=26)	5.19±3.75	7.46±3.09	4.738	<0.001***	0.962	Time	26.080	<0.001***	0.362
	CG (n=22)	5.64±3.47	7.14±2.97	2.637	0.015	0.571	Time×Group	1.086	0.303	0.023
Body mass index	EG (n=26)	5.19±3.96	7.19±4.66	2.271	0.032*	0.449	Time	7.306	0.010*	0.137
	CG (n=22)	4.77±2.84	6.50±4.95	1.600	0.125	0.361	Time×Group	0.039	0.844	0.001

EG: experimental group, CG: control group.
*P<0.05, **P<0.01, ***P<0.001; tested via paired t-test and two-way repeated measures analysis of variance

Discussion

In the present study, we investigated changes in physical fitness following implementation of a virtual reality-based physical education program for 5th and 6th grade elementary school students. First, overall health-related physical fitness scores based on standardized tests of cardiorespiratory endurance, flexibility, muscular strength, endurance, power, and BMI differed significantly between the experimental and control groups among both male and female participants. Specifically, a significant within-group difference was observed within the experimental group but not the control group. In particular, we observed significant differences in time and group interactions, indicating that the virtual reality-based physical education program was effective for the experimental group. These findings are in accordance with previous results highlighting the effectiveness of virtual reality-based physical education for both children and adults (20). Indeed, adult studies have highlighted the ability of such programs to improve cognitive function (21-22), emotional regulation, and dietary habits. Such programs have also demonstrated effectiveness in promoting physical activity and improving both balance and cognitive function in older adults (23). Moreover, virtual reality-based rehabilitation has shown promise in patients with stroke and Parkinson's disease, with effects comparable to or better than those of existing methods (23). Similar to our results, previous studies have reported that such programs can lead to positive attitudes and promote knowledge of movement among students (24-25). Therefore, in addition to being adaptable to each student's developmental level, the program developed in the current study may help to foster kinesthetic awareness based on feedback from motion sensors and cameras.

In the present study, we also observed significant differences in cardiorespiratory endurance between the experimental and control groups for both male and female participants. The significant differences between the groups were ultimately affected by a decrease in the control group rather than an increase in the experimental group. The facility in which the virtual reality-based physical education program was conducted was approximately the size of two regular classrooms, meaning that it was rather narrow compared to a playground or gym. Energy consumption in a gym setting was roughly 4.1±1.1 kcal/min, while that in virtual reality-based physical activity facilities exceeded 3.5±0.9 kcal/min (26). Therefore, despite a significant difference in average cardiorespiratory endurance, other differences may have been nonsignificant due to limitations in the radius of activity and range of motion, given the space limitations (27). However, because energy consumption during virtual reality-based physical activity is much greater than the rate of 0.7±1.3 kcal/min for general living movements such as studying, sleeping, and walking, our results suggest that such programming can aid in improving cardiorespiratory endurance through strategic design (28). In contrast, we observed a significant decrease in cardiorespiratory endurance in the control group. This may be because we included the vacation period in the experimental period, during which factors promoting activity may have been absent. However, we observed no significant decreases in other physical factors. In fact, according to a study investigating changes in physical fitness before and after the COVID-19 pandemic, decreases in cardiorespiratory endurance were most strongly related to decreases in physical activity (18).

Notably, we observed no effect of time or group on flexibility or BMI in boys. Similarly, these variables exerted no effects on power or BMI in girls, suggesting that changes in physical fitness differed according to gender. One study examining differences in exercise performance between boys and girls during adolescence reported relatively better explosive power in the upper and lower extremities among boys, as well as relatively better flexibility and balance among girls (29). These findings suggest that, even when participating in the same program, boys and girls may experience different performance benefits. However, BMI did not significantly differ between boys and girls, despite reports that weight loss is significantly related to food intake and physical activity (30).

Ultimately, our results provide insight into the effects of virtual reality-based physical education among elementary school students in Korea. However, this study included only 5th and 6th grade students from a single region, thus limiting the generalizability of our results. In addition, students who participated in the program tended to have relatively low fitness levels, necessitating further studies to determine whether the same effect can be observed among those with moderate or high physical fitness levels.

Conclusion

Virtual reality-based physical education programs are effective for improving physical fitness among elementary school students. Therefore, such programs may aid in recovering physical fitness status among students who have experienced a deterioration in performance due to the COVID-19 pandemic. Evidence to date suggests such programs can help strengthen cardiorespiratory endurance by increasing energy consumption within a limited physical space. Nonetheless, further studies are required to investigate differential effects between boys and girls, as well as the influence of food intake on weight and other outcomes.

Journalism Ethics considerations

Ethical issues (Including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc.) have been completely observed by the authors.

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Conflict of interest

The authors declare that there is no conflict of interests.

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