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ORIGINAL RESEARCH

Effect of unsupervised Kinect-based mixed reality fitness programs on health-related fitness in men during COVID-19 pandemic: randomized controlled study

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Abstract

This study aimed to investigate the effect of Kinect-based mixed reality (KMR) exercise and unsupervised individual exercise on health-related fitness. A total of 27 participants underwent cardiorespiratory fitness tests for the inclusion criteria and were randomly assigned to three groups: a KMR group (KMRG), an unsupervised individual group (UIG), or a control group (CG). Pre and post-tests were conducted to measure Maximum oxygen uptake (VO_2max), body composition, upper and lower-body (LB) muscle strength, and endurance. KMRG and UIG attended exercise sessions 3 days per week for 8 weeks. KMRG used the KMR device and UIG used an instructive banner for exercise. All groups maintained their daily routines and submitted diet records every 4 weeks. Results showed that VO_2max, upper-body muscle endurance, and LB muscle endurance of knee extension was increased in KMRG and UIG. LB muscle strength in knee flexion was increased in UIG and LB muscle endurance in knee flexion was increased in KMRG. VO_2max, LB muscle strength, and LB muscle endurance were greater in KMRG than in CG. LB muscle strength in knee flexion was greater in KMRG than in UIG. Body fat was increased and skeletal muscle mass was decreased in CG. KMR exercise showed better performance than unsupervised individual (UI) exercise, and the exercise program was effective in both KMR and UI environments. These findings contribute to the growing evidence supporting the use of technology-based exercise interventions as a potential strategy to enhance health-related fitness.

Keywords

Digital health; Fitness program; Kinect; Mixed reality; Unsupervised; Physical fitness

1. Introduction

With the advancements in information and communication technologies, extended reality (XR) techniques, such as virtual reality (VR), augmented reality (AR), and mixed reality (MR), have gained increasing significance in the realm of digital health [1]. These technologies offer promising avenues for enhancing existing healthcare solutions or creating novel ones. Among these devices, the Kinect-based mixed reality device (KMR) stands out, capable of tracking 25 joints of the user's body using a Kinect camera during exercise and providing real-time feedback through AR by converting the Kinect data. This unique interaction between the device and the user creates an immersive MR environment, enabling exercise without the need for human supervision or intervention [2]. Previous studies have demonstrated the superior performance of exercise with feedback compared to non-feedback exercise [3–6], while motion detection has proven effective in guiding exercise routines [7–9]. Additionally, exercising without proper guidance or feedback can potentially lead to injuries [10]. Consequently, the KMR device holds immense potential for individuals who face challenges in accessing professional exercise assistance, offering a beneficial solution to enhance their exercise experience.

Occupations like firefighting demand a high level of physical fitness [11–14], with a minimum VO_2max of 42 mL/kg/min deemed necessary for safety according to the National Fire Protection Association (NFPA) standards. However, a significant majority of Korean firefighters fail to meet this requirement, with 63.9% falling short [1, 15]. Many firefighters also struggle with overweight issues and elevated body fat levels [16], which can increase the risk of injuries and cardiovascular diseases, ultimately affecting their occupational capabilities [17].

Shift work and emergency situations can further impact firefighters' health negatively, but exercise has shown promise in mitigating these effects [18, 19]. Unfortunately, due to the nature of their occupation, most firefighters face constraints in engaging in regular exercise routines [20]. Therefore, there is a pressing need to develop effective and time-efficient fitness programs tailored to Korean firefighters, aiming to prevent injuries and enhance workability [16, 20, 21]. However, no previous study has evaluated the feasibility of non-face-to-face KMR exercise for individuals with limited opportunities to engage in supervised exercise with professionals or access gym or fitness center facilities. Thus, this study aims to compare the effectiveness of KMR exercise and unsupervised individual exercise, evaluating the program's impact on health-related fitness in moderately fit overweight men. We hypothesize that unsupervised KMR exercise will outperform individual exercise and yield improvements in health-related fitness parameters.

2. Methods

2.1 Participant

The sample size calculation was performed using G*Power version 3.1 (Heinrich-Heine-University Düsseldorf, Düsseldorf, Germany) [22, 23]. With an effect size set at 5%, power at 80%, and a two-sided alpha level of 5%, the minimum required sample size per group was determined to be 8. To account for potential dropouts, the sample size was increased by approximately 20%.

The inclusion criteria for this study were as follows: participants aged between 20 and 50 years, with a VO_2max ranging from 35 to 42 mL/kg/min, body mass index (BMI) between 23 and 30 kg/m^2, absence of major diseases (such as Parkinson's disease, cardiovascular disease, diabetes, hypertension, *etc.*), no difficulties in using a treadmill and KMR device, no participation in hormonal or mental therapy, no engagement in moderate to heavy training regularly within the past 3 months, no alcoholism, no dietary supplementation, and non-usage of drugs known to influence muscle metabolism.

2.2 Procedure

The study procedure is outlined in Fig. 1. All tests were conducted at a single laboratory in Seoul, and each test was administered by qualified sports science professionals.

Screening and Pre-test: During the initial visit, screening and pre-testing were performed. Screening involved the administration of the Korean version of the International Physical Activity Questionnaire (IPAQ) [24], a medical health/history questionnaire, and a cardiorespiratory fitness test. Participants who met the inclusion criteria proceeded to the pre-test phase, where data on cardiorespiratory fitness from the screening test were collected. Measurements of body composition, lower body (LB) muscle strength, LB muscle endurance, upper body (UB) muscle strength, and UB muscle endurance were obtained. Following the pre-test, participants were randomly assigned to one of three groups: the Kinect-based mixed reality group (KMRG), the unsupervised individual exercise group (UIG), or the control group (CG), in the order of their registration.

Intervention: The exercise groups commenced their exercise regimen within 5 days after the pre-test. The exercise program consisted of a 22-minute circuit-based whole-body workout. During the first week of the intervention, participants in the KMRG and UIG received supervised training to ensure they performed the exercises correctly within their respective environments. The CG group received a health recommendation and a handbook on muscle stretching.

KMRG: Participants were provided with a login service and an individual ID to access the exercise program through the device. Upon logging in and selecting the displayed program, the exercise would start immediately. Data, such as the number of repetitions, repetition scores, and attendance, were later exported to an online Excel format from the device company's headquarters. The KMR device was capable of counting each repetition of the exercise and tracking the time (see Fig. 2).

UIG: Participants in this group were provided with an informative banner displaying exercise instructions with accompanying pictures and narrative texts. Timers set to 1 minute and 15 seconds were also provided.

Both the KMRG and UIG groups were given attendance worksheets and instructed to record the date and their signatures to verify their visits. These worksheets were collected on a weekly basis. For a more detailed explanation of the exercise program, including repetition, time, exercise types, and information about KMR, please refer to our previous publication [2].

All participants were advised to maintain their regular lifestyle and dietary habits throughout the study period. Dietary habits were assessed using a 3-day recall method, and reminder calls were conducted every 2 weeks to ensure adherence to the study protocol. For the CG group, which might not have participated fully in the study, personal training sessions were offered after the completion of the intervention. This was communicated to the participants prior to the start of the intervention. Post-tests were conducted using the same procedure as the pre-test, following the completion of the intervention period.

2.3 Measurements

Nutrient intake: Participants were requested to maintain a food record for 3 days, including 2 weekdays and 1 weekend day, every 4 weeks for a total of 8 weeks. The collected food records were analyzed using Can Pro 5.0 software (The Korean Nutrition Society, Seoul, Korea) [25]. The analysis included

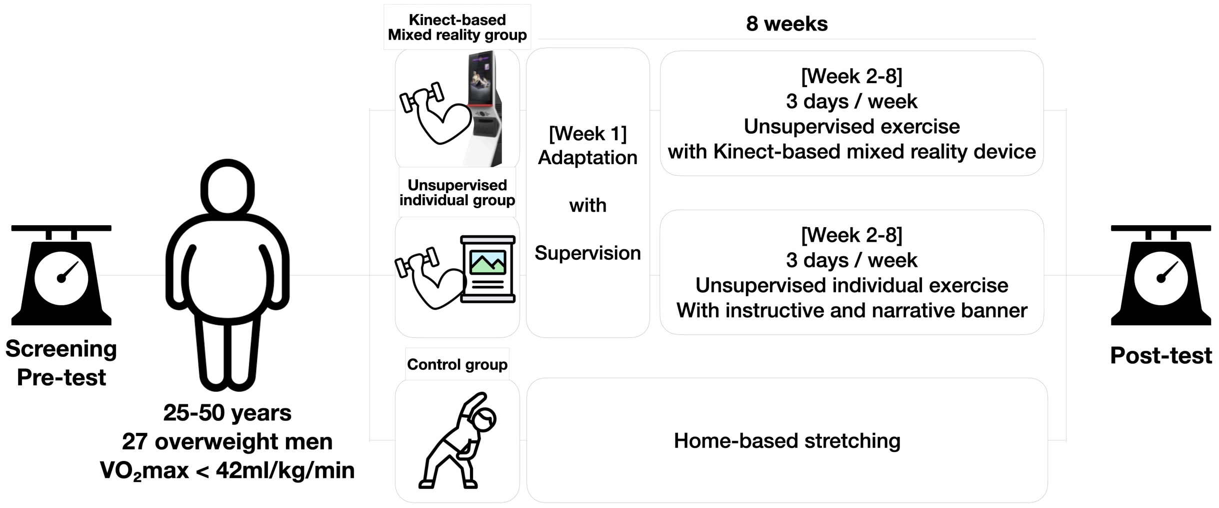

FIGURE 1. Study design for 8 weeks of Kinect-based mixed reality group, unsupervised individual group, and a control group. The study encompassed an 8-week duration, incorporating pre- and post-tests. Participants were randomly assigned to three groups: Kinect-based mixed reality group (n = 9), unsupervised individual group (n = 9), and control group (n = 9). Both the Kinect-based mixed reality group and unsupervised individual group followed a structured exercise program consisting of 3 non-consecutive exercise days per week, while the control group engaged in stretching exercises on 3 non-consecutive days per week for the duration of 8 weeks.

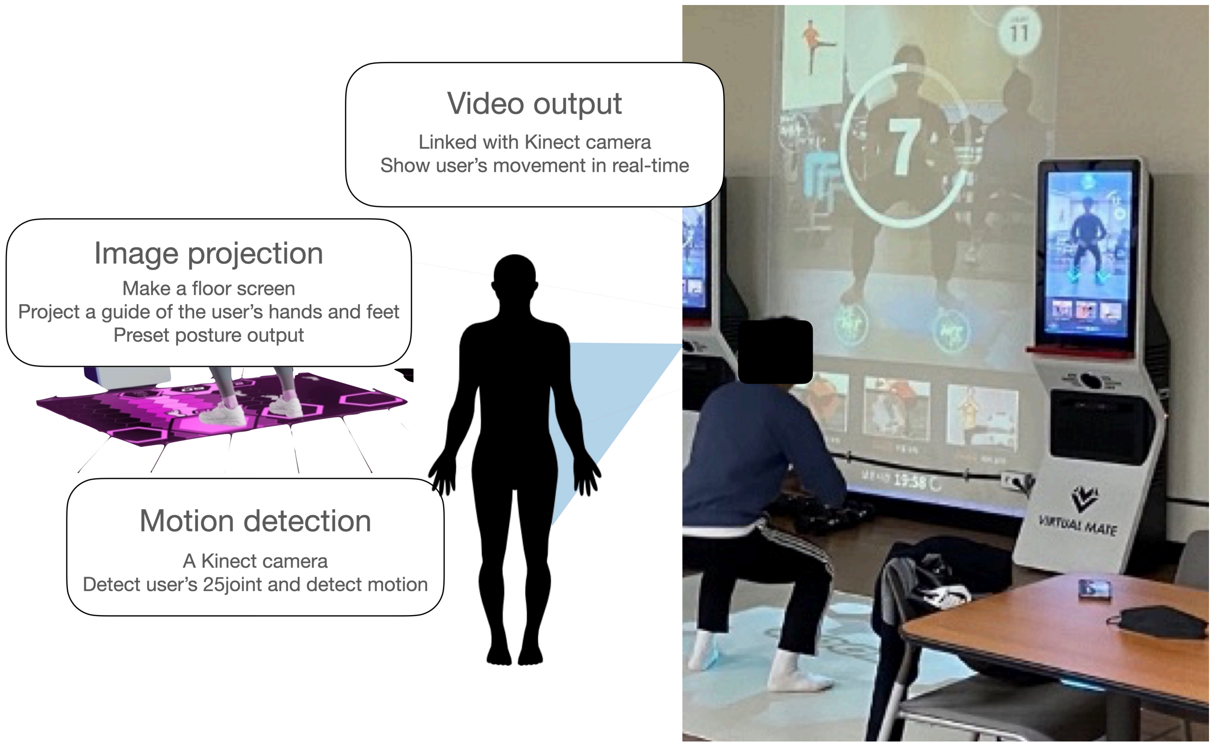

FIGURE 2. An illustration showcasing the functionality of the Kinect-based mixed reality device. The figure depicts the Virtual Mate device (My benefit, Seoul, Republic of Korea) utilized in the study, with accompanying labels highlighting the essential components and features of the equipment.

the calculation of total energy consumption and the energy derived from proteins, fats and carbohydrates.

Body composition: Prior to the measurements, participants were instructed to rest in a seated position for 5 minutes, and their blood pressure was measured using a blood pressure monitor (BPBIO320S, Inbody Co, Seoul, Korea). Height was measured to the nearest 0.1 cm using an extensometer. Body weight (kg), skeletal muscle mass (kg), fat-free mass (kg), and BMI (kg/m^2) were measured using bioelectrical impedance analysis (InBody720, Seoul, Korea). Participants were provided with guidelines for the measurements, which included being in a fasting state prior to the measurement, wearing light clothing, removing all jewelry, and following the instructions provided by the device, such as selecting the appropriate electrodes and maintaining stillness and silence during the measurement.

Cardiorespiratory fitness (VO_2max): The test for cardiorespiratory fitness was conducted using a gas analyzer and treadmill (Quark CPET, COSMED, Italy, Rome) following the standard Bruce protocol [26]. Before the test, a respiratory mask was securely placed on the participant's face to ensure there was no gas leakage. Participants wore a heartbeat strap (H10, Polar, Kempele, Finland) and performed a 1-minute warm-up walk on the treadmill at a speed of 6 km/h. Rated Perceived Exertion (RPE) was recorded every minute using the Borg Scale, which ranges from 6 to 20 [27]. The test was terminated when participants met any of the following criteria: (1) inability to continue, (2) attainment of VO_2 plateau, (3) heart rate exceeding 95% of maximum heart rate (HRmax), (4) RPE of 17 or higher, or (5) Respiratory Exchange Ratio of 1.10 or above [28, 29].

Lower body muscle strength & endurance: The test for lower body muscle strength and endurance was conducted using an isokinetic dynamometer (HUMAC NORM, Computer Sports Medicine Inc., Stoughton, MA, USA) with angular velocities set at 60º/s for 5 repetitions and 180º/s for 15 repetitions of knee movements. A rest period of 1 minute was provided between sets, and the dominant leg of the participants was tested. The tests were performed for both flexion and extension movements. Peak torque (NM) normalized to body weight (kg) (%) was used as the measurement for muscle strength, and total work (J) normalized to body weight (kg) (%) was used for muscular endurance [16, 26].

Upper body endurance: Upper body endurance was assessed using a 2-minute push-up test with a tempo of 80 beats per minute (bpm). The evaluation began from the "up" position, and participants lowered their bodies towards the floor until their chin touched a 10 cm height box. Any repetitions that were not performed with proper posture were not counted [14]. Participants were allowed to take temporary rest if needed and resume the test before the time expired.

Upper body strength: The test for upper body strength involved using a grip dynamometer (TKK-5401, TAKEI Co, Ibaraki, Japan). Participants stood with their feet shoulder-width apart and grasped the handle of the grip dynamometer using their proximal interphalangeal joint. The test was repeated twice on each side, and the average value was calculated. Grip strength was reported in kilograms (kg) [26].

2.4 Statistical analysis

All data were analyzed using Statistical Package for the Social Sciences version 25 (SPSS ver. 25, IBM Corporation, Chicago, IL, USA). Descriptive statistics were reported as mean ± standard deviation (SD). The Shapiro-Wilk test was conducted to assess the normality of the data at baseline. One-way analysis of variance was employed to compare the differences between the three groups at baseline. A factorial ANOVA with repeated measures, considering the factors of time (pre *vs.* post) and group (CG *vs.* UIG *vs.* KMRG), was conducted to examine the differences between treatments. Subsequently, *post hoc* analysis using Bonferroni's test was performed to determine specific pairwise differences, and Cohen's d was calculated to estimate effect sizes when a significant treatment or treatment-by-time interaction was identified. The significance level was set at $p < 0.05$.

3. Results

3.1 Participant

Out of the initial 36 individuals who underwent screening, 7 subjects did not meet the inclusion criteria, and 2 declined to participate in the randomized group (CG). Therefore, a total of 27 participants completed the 8-week intervention (CG = 9, UIG = 9, KMRG = 9). The distribution of participants' characteristics at baseline was found to be normal, and there were no significant differences among the groups (Table 1). The compliance rates for both KMRG and UIG were 94.9% throughout the 8-week intervention. Compliance was calculated as the number of visit days divided by the total number of planned exercise days (8 weeks × 3 days).

3.2 Energy intake

The amount of energy derived from total energy intake among the three groups (CG, UIG, KMRG) is shown in Table 2. There were no significant differences observed between the three groups.

3.3 The effects of exercise on body composition

Body fat percentage (%) showed a significant increase (p = 0.019) over time in the CG, and skeletal muscle mass exhibited a significant decrease (p = 0.038) within the CG. However, there were no significant differences observed between the groups (Table 3).

3.4 The effects of exercise on physical fitness components

There were significant increases over time in VO_2max ($p < 0.001$), UB muscle endurance (p = 0.014), LB muscle endurance in knee extension (p = 0.007), and LB muscle endurance in knee flexion (p = 0.012) observed in the KMRG. The UIG showed significant increases in VO_2max (p = 0.012), UB muscle endurance ($p < 0.001$), LB muscle endurance in knee extension (p = 0.020), and LB muscle strength in knee flexion (p = 0.033) over time. Significant differences between the groups were found in VO_2max (K > C; p = 0.010, I > C;

TABLE 1. Baseline characteristics of the participants.

Variables	CG	UIG	KMRG	F	p
Age (yr)	30.89 ± 0.89	30.22 ± 2.20	29.11 ± 2.30	0.221	0.804
Height (cm)	174.17 ± 1.98	172.4 ± 2.32	173.5 ± 1.57	0.202	0.818
Weight (kg)	79.33 ± 2.97	72.18 ± 2.57	72.89 ± 2.54	2.138	0.140
BMI (m^2/kg)	26.12 ± 2.27	24.29 ± 2.38	24.22 ± 2.90	1.630	0.217
Body fat (%)	22.98 ± 6.26	22.84 ± 5.32	21.33 ± 5.56	0.229	0.797
Skeletal muscle (kg)	34.62 ± 2.93	31.38 ± 3.55	32.23 ± 3.10	2.472	0.106

Values are presented as mean ± standard deviation.
CG, Control Group; UIG, Unsupervised Individual Group; KMRG, Kinect-based Mixed Reality Group. BMI: Body Mass Index.

TABLE 2. Energy intakes during intervention between three groups.

Variables	CG	UIG	KMRG	F
Energy (kcal/d)	2144.20 ± 226.84	2004.62 ± 294.44	2152.67 ± 199.45	1.049
Carbohydrate (g/d)	294.86 ± 45.67	269.49 ± 61.88	273.88 ± 54.02	0.562
Protein (g/d)	81.69 ± 8.44	81.42 ± 11.72	92.31 ± 20.84	0.935
Fat (g/d)	64.78 ± 11.39	61.30 ± 13.54	69.37 ± 12.67	1.619

Values are presented as mean ± standard deviation.
CG, Control Group; UIG, Unsupervised Individual Group; KMRG, Kinect-based Mixed Reality Group.

TABLE 3. Body composition of KMRG, UIG and CG before and after the intervention.

Variables	CG	UIG	*Post-hoc*[1]	KMRG	*Post-hoc*[2]	*Post-hoc*[3]
Weight (kg)						
Pre	79.33 ± 8.92	72.18 ± 7.72		72.89 ± 7.60		
Post	79.19 ± 8.82	72.69 ± 8.32	0.108	73.22 ± 7.70	0.138	0.892
p^4	0.769	0.303		0.499		
BMI (kg/m²)						
Pre	26.12 ± 2.27	24.29 ± 2.38		24.22 ± 2.90		
Post	26.07 ± 2.48	24.50 ± 2.44	0.214	24.30 ± 2.87	0.163	0.872
p^4	0.723	0.186		0.620		
Body fat (%)						
Pre	22.98 ± 6.26	22.84 ± 5.32		21.33 ± 5.56		
Post	24.17 ± 6.09	22.72 ± 5.46	0.598	21.31 ± 5.64	0.301	0.606
p^4	0.019 (−0.193)[5]	0.798		0.963		
Skeletal muscle mass (kg)						
Pre	34.62 ± 2.93	31.38 ± 3.55		32.23 ± 3.10		
Post	33.88 ± 2.77	31.42 ± 3.80	0.730	32.52 ± 3.58	0.885	0.840
p^4	0.038 (0.260)[5]	0.897		0.402		

Values are presented as mean ± standard deviation.
[1]*, this present p-value compared between CG and UIG;* [2]*, this present p-value compared between CG and KMRG;* [3]*, this present p-value compared between UIG and KMRG;* [4]*, this present p-value of comparison between pre and post;* [5]*, this present Cohen's d.*
CG, Control Group; UIG, Unsupervised Individual Group; KMRG, Kinect-based Mixed Reality Group. BMI: Body Mass Index.

$p = 0.040$), LB muscle strength in knee extension (K > C; $p = 0.008$), LB muscle strength in knee flexion (K > I; $p = 0.021$, K > C; $p = 0.0035$), LB muscle endurance in knee extension (K > C; $p = 0.018$), and LB muscle endurance in knee flexion (K > C; $p = 0.026$) (Table 4).

4. Discussion

In this study, we examined the effectiveness of KMR compared to unsupervised individual exercise in the context of the COVID-19 pandemic. The results indicate that KMR is a highly effective tool for delivering a fitness program, leading to significant improvements in muscle strength and endurance compared to unsupervised exercise. These findings have important implications for promoting physical activity and enhancing overall health, particularly in situations where access to supervised exercise is restricted.

Previous research has consistently demonstrated that exercises with feedback are more effective and efficient compared to exercises without feedback. For instance, studies have shown that wrist-injured patients who used a live-feedback program for rehabilitation achieved faster recovery compared to those who did non-feedback exercises [6]. Similarly, visual live feedback has been found to improve speed in the "3RM squat" among female athletes compared to exercises without feedback [30, 31]. In this study, we observed that the KMRG

TABLE 4. Physical fitness components of three groups before and after the intervention.

Variables	CG	UIG	*Post-hoc*[1]	KMRG	*Post-hoc*[2]	*Post-hoc*[3]
VO_2max (mL/kg/min)						
Pre	36.66 ± 3.94	36.21 ± 3.40		34.79 ± 4.09		
Post	35.24 ± 3.88	39.14 ± 3.77	0.040 (−1.020)[5]	40.27 ± 3.78	0.010 (−1.313)[5]	0.538
p^4	0.201	0.012 (−0.816)[5]		<0.001 (−1.391)[5]		
Hand grip (kg)						
Pre	41.09 ± 6.80	38.29 ± 4.10		43.32 ± 6.89		
Post	40.88 ± 5.26	39.82 ± 3.08	0.674	44.21 ± 6.75	0.191	0.089
p^4	0.823	0.113		0.349		
2-min Push-up (rep)						
Pre	40.00 ± 14.47	33.89 ± 15.14		41.22 ± 7.46		
Post	39.78 ± 10.94	42.44 ± 11.92	0.611	46.67 ± 8.49	0.196	0.423
p^4	0.915	$p < 0.001$ (−0.628)[5]		0.014 (−0.682)[5]		
Knee 60° ext peak torque (NM)						
Pre	225.56 ± 27.77	222.33 ± 64.40		241.33 ± 47.99		
Post	205.89 ± 31.50	230.44 ± 35.22	0.160	254.44 ± 40.39	0.008 (0.735)[5]	0.169
p^4	0.169	0.564		0.354		
Knee 60° flex peak torque (NM)						
Pre	105.78 ± 29.60	92.89 ± 28.70		117.78 ± 25.73		
Post	108.78 ± 21.37	111.00 ± 21.53	0.815	132.00 ± 21.53	0.021 (−1.082)[5]	0.035 (−0.975)[5]
p^4	0.711	0.033 (−0.714)[5]		0.088		
Knee 180° ext. total work (J)						
Pre	1244.22 ± 239.22	1117.89 ± 320.47		1283.11 ± 331.10		
Post	1174.11 ± 207.00	1309.11 ± 375.62	0.318	1511.00 ± 229.90	0.018 (−1.540)[5]	0.140
p^4	0.369	0.020 (−0.548)[5]		0.007 (−0.800)[5]		
Knee 180° flex. total work (J)						
Pre	586.89 ± 249.94	502.67 ± 215.80		571.22 ± 153.50		
Post	537.44 ± 140.02	572.11 ± 204.55	0.655	718.56 ± 132.60	0.026 (−1.328)[5]	0.068
p^4	0.369	0.211		0.012 (−1.027)[5]		

Values are presented as mean ± standard deviation.
[1], this present p-value compared between CG and UIG; [2], this present p-value compared between CG and KMRG; [3], this present p-value compared between UIG and KMRG; [4], this present p-value of comparison between pre and post; [5], this present Cohen's d.
ext., extension; flex., flexion; CG, Control Group; UIG, Unsupervised Individual Group; KMRG, Kinect-based Mixed Reality Group.

group exhibited smaller effects compared to previous studies that utilized real-time feedback. Only one factor, specifically 60º of knee flexion, showed a significant difference compared to the UIG group. However, over time, KMRG demonstrated more significantly enhanced factors compared to UIG. Additionally, KMR may offer an advantage in improving lower body strength due to its counting system, which only recognizes repetitions performed with proper form and range of motion. When compared to the CG that followed the same fitness program for the same duration, UIG showed a significant difference only in VO_2max. On the other hand, KMRG exhibited significant differences in Knee 60º flex peak torque (NM), Knee 180º ext total work (J), and Knee 180º flex total work (J) over time. Overall, KMRG and UIG followed the same fitness program, but KMRG demonstrated superior performance compared to UIG throughout the 8-week intervention. These findings suggest that KMR is an effective device for delivering fitness programs. However, further studies with larger sample sizes, and a broader range of population and fitness programs are necessary to fully understand its effects.

In our previous study, we determined that the exercise program had a moderate-to-high intensity level suitable for Korean men, with a VO_2max range of 35–42 mL/kg/min, and we established the reliability of the KMR device [2]. In this current study, our objective was to evaluate the long-term effects and usability of KMR by implementing the same fitness program over an 8-week period. While there were no significant differences in terms of body composition among the groups, we observed a significant decrease in skeletal muscle mass and an increase in body fat percentage in the control group over time. Interestingly, the exercise program appeared to prevent the increase in body fat percentage and the loss of skeletal muscle mass in the exercise groups, which aligns with findings from previous studies conducted on firefighters [18, 32]. Although there were no significant differences in nutritional intake between the groups, the exercise program seemed to have a positive effect on body composition by maintaining body fat and skeletal muscle mass without the need for calorie restriction.

The study demonstrated significant improvements in VO_2max for both the KMRG and UIG groups compared to the control group and baseline measurements. The baseline VO_2max was recorded at 31.11 mL/kg/min, while after the intervention, the KMRG group showed an average of 40.27 mL/kg/min, and the UIG group showed an average of 39.14 mL/kg/min. Although the achieved VO_2max values did not meet the minimum standard set by the National Fire Protection Association (NFPA), the results indicated a significant increase within the exercise groups. While handgrip strength did not show significant improvement, other fitness components displayed notable enhancements in both KMRG and UIG, which aligns with findings from previous studies [19, 33]. The standardized exercise program utilized a consistent external weight and placed emphasis on maintaining proper posture to ensure safety. Additionally, the program gradually increased the number of repetitions to enhance participants' fitness abilities. These findings suggest that focusing on increasing repetitions rather than load may be a safer and more effective approach, particularly for beginners [34, 35].

While our study provides valuable insights into the effectiveness of the exercise program, there are several limitations that should be considered when interpreting the findings. First, it is important to note that the participants in our study were not actual firefighters (FFs) due to COVID-19 restrictions. However, the study aimed to assess whether the exercise program could improve the health-related fitness of participants who had similar body composition and VO_2max levels as Korean FFs. It is worth considering the potential variations in results when applied to real FFs in operational settings. Second, we did not include qualitative measurements to examine whether the participants' interest in the new equipment influenced the differences in effectiveness between the UIG and KMRG. Nevertheless, the high attendance rates and achievement of minimum repetitions indicate that participants were actively engaged and enthusiastic about the program.

Future studies could address these limitations by recruiting real FFs as participants, including female participants to assess sex-specific effects, increasing the sample size for improved statistical power, incorporating qualitative measurements to explore participants' experiences and perceptions, developing diverse content tailored to different characteristics (*e.g.*, fitness, age, occupation, *etc.*) and extending the intervention duration to evaluate longer-term effects.

5. Conclusions

In conclusion, this study represents the first attempt to compare the effects of an exercise program using two different modes: Kinect-based mixed reality and unsupervised individual exercise. The results demonstrate that the exercise program inserted in the KMR was effective in improving health-related fitness parameters. Furthermore, the KMR showed greater efficiency compared to unsupervised individual exercise, despite both groups following the same exercise program. These findings highlight the potential benefits and usability of KMR in promoting physical activity and improving health-related fitness. Future studies should aim to investigate the effectiveness and usability of the exercise program using Kinect-based mixed reality (KMR) with diverse populations and different exercise content.

AVAILABILITY OF DATA AND MATERIALS

The data presented in this study are available on reasonable request from the corresponding author.

AUTHOR CONTRIBUTIONS

SYA, BGL, YSA and WS—designed this study. SYA and YHS—curated data. SYA and JHB—analyzed the data. SYA, YHS, XXL and DHK—performed the research. SYA—wrote the manuscript. SYA, JHB and BGL—revised the manuscript. WS—approved the final manuscript. YSA, WS, DIS, JJP, HJK, HJL and CGL—got the funding. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This research was reviewed and approved by the institutional review board of Yonsei University (#CR318031). The trial was conducted according to the ethical principles of the Helsinki Declaration. Informed consent was obtained from all participants.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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