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Augmented Reality Training on Combat Sport: Improving the Quality of Physical Fitness and TechnicalPerformance of Young Athletes

Entrenamiento con realidad aumentada en deportes de combate: mejora de la calidad de la aptitudfísica y el rendimiento técnico de los atletas jóvenes

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Abstract. This study aims to analyze the effects of augmented reality (AR) training in improving physical fitness and technical performance. An 11-week randomized controlled design was adopted in this study. This research involved sixty female athletes in Pencak Silat and Karate from Sriwijaya University (Indonesia). Participants were allocated into the experimental group, namely AR (Pencak silat: n=15, Karate: n=15) and control group (Pencak silat: n=15, Karate: n=15). Handgrip dynamometer, leg dynamometer test, medicine ball, standing long jump test, hexagon agility test, sit and reach test and multi stage test are used to measure physical fitness levels while the target punching test and target kick test are used to measure technical performance. The results of Student's t showed that there was a change in the mean value of AR (all, $p < 0.05$) and control only in MBT ($p < 0.05$) from baseline to final-test, ANOVA analysis we observed that there was an effect of Time on physical fitness (all, $p < .001$), there was a Group effect related to HDT ($p< .001$), MBT ($p = 0.043$), SART ($p < .001$), and MST ($p < .001$) and there was a Time * Group interaction related to HDT ($p < .001$), LDT ($p = 0.029$), SLJT ($p < .001$), HAT ($p < .001$), SART ($p < .001$), and MST ($p < .001$), there was an effect of Timeon technical performance (all, $p < .001$), Group effect related to TPT ($p = 0.004$), and Time * Group interaction related to TPT ($p= 0.001$) and TKT ($p < .001$). Thus, we conclude that using AR for 11 weeks is an effective training method for improving the qualityof physical fitness and technical performance of young athletes in combat sports.
Keywords: Combat sport, Athlete performance, Technology training.

Resumen. Este estudio tiene como objetivo analizar los efectos del entrenamiento con realidad aumentada (RA) en la mejora de la condición física y el rendimiento técnico. En este estudio se adoptó un diseño controlado aleatorio de 11 semanas. En esta investigación participaron sesenta atletas de Pencak Silat y Karate de la Universidad de Sriwijaya (Indonesia). Los participantes fueron asignados al grupo experimental, a saber, AR (Pencak silat: n=15, Kara-te: n=15) y al grupo de control (Pencak silat: n=15, Karate: n=15). El dinamómetro de agarre manual, la prueba del dinamómetro de piernas, el balón medicinal, la prueba de salto de longitud de pie, la prueba de agilidad hexagonal, la prueba de sentarse y alcanzar y la prueba de múltiples etapas se utilizan para medir los niveles de aptitud física, mientras que la prueba de puñetazo y patada se utilizan para medir los niveles técnicos actuación. Los resultados de la t de Student mostraron que hubo un cambio en el valor medio de AR (todos, $p < 0,05$) y control solo en MBT ($p < 0,05$) desde el inicio hasta la prueba final, el análisis ANOVA observamos que hubo un efecto del tiempo sobre la aptitud física (todos, $p < .001$), hubo un efecto de grupo relacionado con HDT ($p < .001$), MBT ($p = 0.043$), SART ($p < .001$) y MST ($p < . 001$) y hubo una interacciónTiempo * Grupo relacionada con HDT ($p < .001$), LDT ($p = 0.029$), SLJT ($p < .001$), HAT ($p < .001$), SART ($p < .001$) , y MST ($p < .001$), hubo efecto de Tiempo sobre el desempeño técnico (todos, $p < .001$), Efecto de grupo relacionado con TPT ($p = 0.004$) y Tiempo * Interacción de grupo relacionado con TPT ($p = 0,001$) y TKT ($p < .001$). Por lo tanto, concluimos que el uso de AR durante 11 semanas es un método de entrenamiento eficaz para mejorar la calidad de la condición física y el rendimiento técnico de los atletas jóvenes en deportes de combate.
Palabras clave: Deporte de combate, Rendimiento del deportista, Entrenamiento tecnológico.

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Introduction

In the modern era, technology that has been used in sev-eral sectors such as physical education (Jastrow et al., 2022; Marín-Suelves et al., 2023; Ridwan et al., 2023; Zulkifli & Danis, 2022), health (Baashar et al., 2023; Kan Yeung et al., 2021; Rodríguez-Abad et al., 2021; Seals et al., 2021), busi-ness (Capasa et al., 2022; Rauschnabel et al., 2022), sports (Badau et al., 2023; Pu & Yang, 2022; Witte et al., 2022) encountered a significant increase in several countries. Datashowed that using technology could provide benefit, which can help athletes to achieve their goals optimally (Jumareng et al., 2021; Jumareng et al., 2022). In sports, technologyhas been started to be adapted and applied by coaches (Muktiani et al., 2022; Witte et al., 2022), in order to gain the highest achievements. Technology today becomes more popular and trending in several types of sports (Lee & Oh, 2022; Pitsiladis, 2023; Zhang & He, 2022) is augmented reality (AR). AR can be interpreted as an advanced technol-ogy that combines real world conditions with 3D animation elements (Al-Ansi et al., 2023; Martin et al., 2023; Reeves et al., 2021; Uhlendorf & Uhrich, 2022). According to Loia and Orciuoli (2019), AR could integrate an avatar created by a computer, as if it has entered a real environment or conditions. Training in combat sports such as Pencak silat or Karate, through AR application can provide an authentic and new experience for athletes, because they

learn move- ment skills by an animation (virtual avatar) that appear in the real world (Lee & Oh, 2022). In addition, sophisticated AR technology can provide guidance and simulation of physical experiences for users (Baashar et al., 2023). AR has been proven based on previous studies to increase Chinese athletes' interest in extreme sports (Zhang & He, 2022),and AR is believed to have advantages in improving aca- demic aspects and self-efficacy (O'Connor & Mahony,2023). Despite this, there is limited coaches who apply AR to improve the quality of physical fitness and technical per- formance in combat sports athletes. In fact, currently com-bat sports have high competitive competition to achieve peak performance (Barley & Harms, 2021), so that it de- mands physical fitness (Podrigalo et al., 2022), and high technical performance in athletes (Kudryavtsev et al., 2023).

Physical fitness is an important element in combat sportsand as a determining factor in an athlete's success. Basically,
physical fitness is related to the quality of endurance (Gani et al., 2023), strength (Do Nascimento et al., 2023), power, speed, agility (Ben Hassen et al., 2022; Kabadayı et al., 2022; Ojeda-Aravena et al., 2023), which should be gained by combat sports athletes. Data from previous stud- ies reported that a prerequisite for achieving optimal results in combat sports is to improve physical fitness (Cid-Calfucura et al., 2023). Meanwhile, poor physical fitness could be a factor in reducing performance (Kudryavtsev et al., 2023). The characteristic of combat sports is it has high intensity, so an athlete needs good physical fitness, to gen- erate explosive punching and kicking movements (Barley et al., 2019). Another benefit of maintaining high physical fit-ness is to avoid fatal injuries (Xiao et al., 2021). On the other hand, physical fitness enable athletes to fight in a longer duration, without get excessive fatigue (Isnaini et al., 2023). Rutkowski et al., (2019), explained that improving physical fitness is an effective way to create physical health. Technical performance is the second factor that is very important for combat sports athletes to support their per- formance in the competition (Zadorozhna et al., 2020;Zadorozhna et al., 2020). Technical performance is related to the quality of attacking movements such as punches andkicks to blocks and defensive locks (Barley & Harms, 2021). Improving technical skills could support athletes to gainhigh performance, and has a great chance to win the com-petition (Ribas et al., 2020). Data from a previous study reported that in combat sports competition, athletes must carry out motoric actions in attacking and defending for 3 rounds of 5 minutes each, which means that the quality oftechnical performance is a crucial factor (Folhes et al.,2023; Manolachi et al., 2023). However, if athletes havepoor technique, they will be difficult to win (Herrera-
Valenzuela et al., 2021).

There are many international documentation about AR research (Al-Ansi et al., 2023; Çetin & Türkan, 2022; Elmqaddem, 2019; da Silva et al., 2019; Loia & Orciuoli, 2019; Petrov & Atanasova, 2020; Rodríguez-Abad et al., 2022), but previous studies have weakness which is only fo- cus on applying AR in physical education classes (Liang etal., 2023; Moreno-Guerrero et al., 2020; Mokmin & Rassy, 2022; Viscione & D'elia, 2019; Widyaningsih et al., 2023), but there is still limited AR research in the context of combat sports training. Considering this gap, our re- search offers something new, namely applying AR to im- prove the quality of physical and technical fitness among young athletes in the context of combat sports, namely Pen- cak Silat and Karate. This research has potentially contrib- uted to innovation in combat sports training as an effort to improve and develop the quality of physical fitness and tech- nical performance in the current era and in the future. Therefore, our study aims to investigate the effects of an ARprogram on physical fitness and technical performance among young athletes in combat sports.

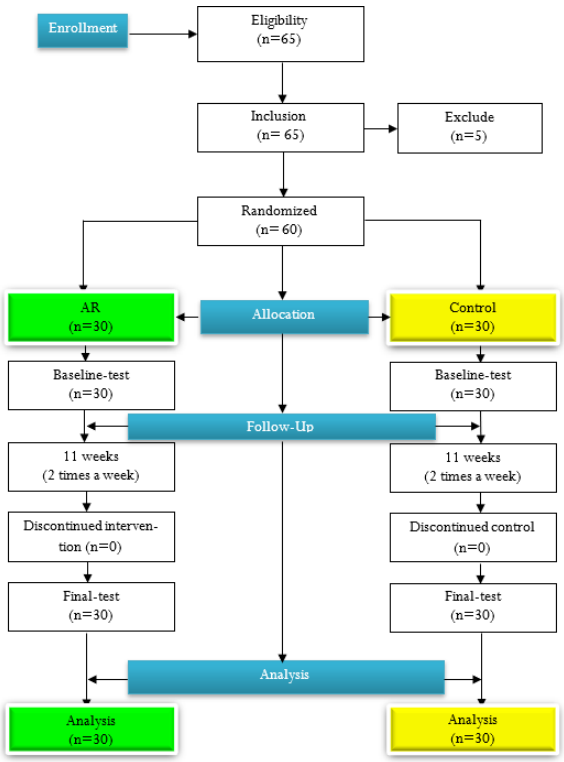

Figure 1. CONSORT flow chart

Material and methods

Participants

We involved female athletes from the Pencak silat (n=30) and Karate (n=30) who were studied in Sriwijaya University (Indonesia). They were selected by following theinclusion criteria, namely: (i) They did not participate inother activities outside the AR program, (ii) They did not get injuries. Meanwhile, the exclusion criteria are: (a) par- ticipating in championships at national or international level, (ii) injury in the last 3 months. We calculated apriorithe power statistics using G*Power (v. 3.1.9.7). A sample size of at least 30 participants was required to have sufficient power (>0.80) based on a chosen alpha of 0.05 (See CON- SORT Fig. 1). After randomization, athletes were allocated into the experimental group, namely AR (Pencak silat: n=15,

Karate: n=15) and control groups (Pencak silat: n=15, Karate: n=15) by using random analysis (https://www.randomizer.org/). Information regarding age, height, weight, types of combat sports, training experienceand BMI of the participants is shown in Table 1.

Table 1.
Information from AR and control groups

Characteristic	AR (n = 30)	Control (n = 30)	Total (n = 60)
Age (year)	17.97 ± 1.09	18.80 ±1.21	18.38 ± 1.22
Height (cm)	164.07 ± 3.46	164.90 ± 3.88	164.48 ± 3.67
Weight (kg)	57.00 ± 1.94	58.57 ± 2.34	57.78 ± 2.27
Types of Combat Sports			
Pencak silat	15(50%)	15(50%)	30(50%)
Karate	15(50%)	15(50%)	30(50%)
Training Experience			
One year	21(70%)	23(77%)	44(73%)
Two year	9(30%)	7(23%)	16(27%)
BMI (kg/m²)	21.27 ± 1.31	21.83 ± 1.34	21.55 ± 1.34

Note: AR: Augmented reality, BMI: Body mass index.

Measures

Physical Fitness

The instruments used to assess physical fitness of combatsports athletes include the following test items:

Strength: Handgrip dynamometer and leg dynamometer test (kg) The instrument used to assess upper muscle strength is the handgrip dynamometer test (Do Nascimento et al., 2023). First, the participants were in a standing position and the arm were straightened beside the body while holding a handgrip. After researcher instructed "Go", the participant gripped as hard as possible until the dynamometer sounded. Participants were given three chances and the highest score was selected as data for analysis. In this study, the handgrip dynamometer test has an inter class correlation (ICC) =

0.80. Meanwhile, the leg dynamometer test was used to as-sess the muscle strength of the lower legs (Isnaini et al., 2023). Participants stood on a leg dynamometer, both hands holding the iron handle, body upright, legs bent 45 degrees. After researcher instructed “Go”, participants pulled the handle as hard as possible and straightened their knees until they stood up straight. Participants had three chances and the best score was selected. Through this research, the leg dynamometer test was tested to have ICC = 0.83.

Power: Medicine ball and standing long jump test (cm)

The arm power component was assessed using the medicine ball test. Participants sat on the floor with their bodies upright, leaning against the wall and both arms holding a medicine ball at their chest. After a signal from the researcher, participants threw the ball with their arms straight forward. Participants had three chances and the result of the furthest throw was taken as the final score. This instrument had ICC = 0.85. Meanwhile, leg power was assessed through the standing long jump test and this instrument had an ICC =

0.90. The method was the participant stood behind the jump line. After researcher instructed “Go”, participants jumped asfar as possible. Participants were given three chances and theresult of the farthest jump was taken as the final score (Do Nascimento et al., 2023).

Speed and Agility: Hexagon agility test (s)

In this study we used the Hexagon agility test to assess speed and agility components (Chen et al., 2021), and this instrument has an ICC = 0.86 (Boutios et al., 2021). Participants stood in the middle of the hexagon and face towards line A. If the researcher instructed "Go", the participant jumped as quickly as possible across line A and returned to the center, then jumped across line B and returned to the center, then crossed line C and returned to the center and so on until the participant jumped over line A and returned to the center again, counting as one lap. After the participant had completed three laps, the stopwatch was stopped and the time was recorded.

Flexibility: Sit and reach test (cm)

The flexibility component was analyzed through the sit and reach test which had an ICC = 0.84. First, the participants sat on the floor with both legs straight until touched the surface of the table and both hands kept on the table. After the "Go" instruction, participants slowly bent their bodiesand hands trying to reach the measuring line as far as possible. The assessment was carried out by measuring the farthest distance (Isnaini et al., 2023).

Endurance: Multi-stage test (ml/kg/min)

In this study, the Multi-stage test was adopted to assess athletes' endurance levels and based on previous studies the instrument had an ICC of 0.82 (Isnaini et al., 2023). First,the participant stood at cone A and after hearing a "blip" sound from the audio recording, the participant ran as fast aspossible to cone B and the distance between each cone was20 meters. The running activity was carried out continuously until the participant was no longer able to run or the partici-pant was unable to adjust to the speed of the sound in the audio recording. The assessment was carried out by calculat-ing the number of running levels or $V02^{max}$.

Technical Performance

Meanwhile, the instrument for measuring technical performance include the following test items:

Target punching test (rep)

In this study, we adopted the Target Punching Test (TPT) from a previous study which had an ICC = 0.85 (Yi et al., 2022). This instrument aims to measure an athlete's hitting ability. This test was carried out by punching the target (pacing pad) as many times as possible in 1 minute. The assessment was carried out by counting the number of punches that hit the target.

Target kick test (rep)

In this study, the Target Kick Test (TKT) was adopted (Kabadayı et al., 2022) in combat sports, namely pencak silat and karate. In this test, participants carried out five sets of kicks. After researcher instructed "Go", participants were required to kick the target (pacing pad) as many times as possible for 10 seconds in one set. Assessment was conducted by counting the number of kicks in each set and adding them up.This instrument was proven to have ICC = 0.85.

Design and Procedure

An 11-week randomized controlled design was adopted in this study and was conducted from September-November 2023 at Sriwijaya University (Indonesia). This research was carried out twice a week, namely on Monday and Thursday. The first meeting was held on Monday (04 September 2023), all participants carried out a baseline test, namely measuring physical fitness and technical performance from 09.30-11.00 am. The second meeting was held on Thursday (07 September 2023), the experimental group carried out the AR program while the control group only carried out usual training activities such as: running, push-ups, technical training directly with a coach (non-AR). The AR and control activities were carried out until Tuesday (13 November 2023) from 09.00-10.00 am. The final meeting was held on Thursday (16 November 2023), all participants carried out a final-test, namely measuring physical fitness and technical performance from 12.00-14.00 noon.

Table 2.
AR training program for Combat Sport.

1-11week				
		Monday	Thursday	Activity example
Type	Duration	Type of exercise	Type of exercise	
Initial activity	5 minute	Warming-up	Warming-up	
Activity	50 minutes	Coach: EK AR training for physical fitness: • Athletes analyzed physical fitness exercises in AR: plank, mt. climber, squat jump, push-up,jumping jack.	Coach: MGS AR training for technical ıance: Athletes analyzed technical drillsin AR: punching and kicking techniques.	
		• Athletes Conducted physical fitness exercises in AR.	Athletes carried out punch and kick technique exercises in AR.	
Last activities	5 minutes	Cooling-down	Cooling-down	

Intervention Program

The AR program was held on Monday and Thursday at 09.00-10.00 am at the Sriwijaya University Gymnasium. Athletes carried out several activities include: (i) waming-up,

(ii) AR training and (iii) cooling-down. Initial "EK" was used to the trainer who trained physical fitness. EK was national level trainer with 15 years coaching experiences. Initial "MGS" was used to the trainer who trained technical perfor-mance. MGS was a national trainer with 25 years of coaching experience. The detail information of AR training program ispresented in Table 2.

Ethical Considerations

All participants had read the rules in this research and agreed to be involved in this research by signing a letter of willingness to become participants. In addition, this research was carried out in accordance with Helsinki guidelines and the protocol was approved by the Ethics Committee of Sriwijaya University (Indonesia) with number: 605/LPPM-UNSRI/2023).

Statistical Analysis

Descriptive statistic was presented as the mean (M) ± standard deviation (SD) of all calculated study variables. Normality testing used the Kolmogorov–Smirnov test and the results proved that all variables showed normal distribution. Student's t statistical analysis was differences meanin physical fitness and technical performance in the baseline-test and final-test stages between the AR and control groups. A two-way repeated measures ANOVA (2 Groups: AR vs control × 2 Times: baseline-test vs final-test), Time*Groups interaction was also calculated to compare the results on physical fitness and technical performance. The effect size test uses the Cohen (d) formula as follows: trival: 0.00-0.19, small effect: 20-49, moderate effect: 50-79, high effect: 0.80 > (Resita et al., 2023). The η2p value is between 0.01 to 0.06 (small), 0.06 > to 0.13 (medium) and the value 0.14 > (large). All data were processed using Jamovi v.2.3.28 statistical software and $p < 0.05$ was set as the significance level.

Results

The Effect of AR on Physical Fitness

Data in Table 3 shows that AR has a significant differences on physical fitness in all components such as: handgrip dynamometer test (HDT) (t = -8.42, p < .001, d = --2.17), leg dynamometer test (LDT) (t = 4.79, p < .001, d

= - 1.24), medicine ball test (MBT) (t = 3.06, p = 0.003, d = -0.78), standing long jump test (SLJT) (t = -7.49, p

< .001, d = -1.93), hexagon agility test (HAT) (t = 6.21, p < .001, d = 1.60), sit and reach test (SART) (t = -7.34, p < .001, d = -1.90), and multi-stage test (MST) (t = -11.9, p < .001, d = -3.08). Meanwhile, the control group had no significant differences on HDT (t = -2.01, p =0.221, d = -0.32), LDT (t = 181, p = 0.076, d = -0.46),

SLJT (t = -1.99, p = 0.051, d = -0.51), HAT (t = -0.554, p = 0.582, d = -0.14), SART (t = -0.121, p = 0.904, d = -0.03), MST (t = -0.377, p = 0.708, d = -0.09) and only has a significant differences on physical fitness related to MBT (t = -2.99, p = 0.004, d = -0.77).

Table 4 shows the results of ANOVA analysis with 2 ×2 repeated measures, we observed that there was an effect of Time on physical fitness (all, p < .001), there was a Group effect related to HDT (p < .001), MBT (p = 0.043) , SART (p < .001), and MST (p < .001) and there was a Time * Group interaction related to HDT (p < .001), LDT (p = 0.029), SLJT (p < .001), HAT (p < .001), SART (p < .001), and MST (p < .001).

Effects of AR on Technical Performance

In Table 3, the AR group has more significant differences on technical performance on TPT (t = -4.08, p < .001, d = -1.05) and TKT (t = -3.35, p = 0.001, d = 0.86) compare

to the control group, which obtain TPT (t = -0.493, p >0.05, d = -0.12 and TKT (t = -1.03, p >0.05, d = 0.26). Based on Table 5 showing the results of ANOVA analy- sis with 2 × 2 repeated measures, we observed that therewas an effect of Time on technical performance (all, p < .001), there was a Group effect related to TPT (p = 0.004), and there was a Time * Group interaction related to TPT (p = 0.001) and TKT (p < .001).

Table 3.
Comparison effects on physical fitness and technical performance at the baseline-test and final-test between two groups

Variables		AR (n = 30)				Control (n = 30)			
	Stage	M ± SD	t	p	ES (d)	M ± SD	t	p	ES (d)
Physical Fitness									
HDT (kg)	Baseline Final	22.7 ± 1.66 30.4 ± 4.75	-8.42	< .001*	-2.17	23.5 ± 2.29 24.2 ± 22.09	-2.01	0.221	-0.32
LDT (kg)	Baseline Final	21.0 ± 2.11 24.0 ± 2.71	-4.79	< .001*	-1.24	21.0 ± 3.11 22.2 ± 1.88	-181	0.076	-0.46
MBT (cm)	Baseline Final	206 ± 35.5 231 ± 27.5	-3.06	0.003*	-0.78	221 ± 36.1 243 ± 17.6	-2.99	0.004*	-0.77
SLJT (cm)	Baseline Final	193 ± 25.9 240 ± 22.7	-7.49	< .001*	-1.93	200 ± 25.1 213 ± 27.0	-1.99	0.051	-0.51
HAT (s)	Baseline Final	75.0 ± 8.04 64.5 ± 4.65	6.21	< .001*	1.60	72.6 ± 10.4 74.0 ± 9.19	-0.554	0.582	-0.14
SART (cm)	Baseline Final	5.03 ± 1.27 7.20 ± 0.99	-7.34	< .001*	-1.90	4.77 ±1.19 4.80 ± 0.925	-0.121	0.904	-0.03
MST (ml/kg/min)	Baseline Final	25.3 ± 1.84 32.7 ± 2.85	-11.9	< .001*	-3.08	25.2 ± 2.09 25.4 ± 2.03	-0.377	0.708	-0.09
Technical performance									
TPT (rep)	Baseline Final	11.5 ± 1.38 12.9 ± 1.34	-4.08	< .001*	-1.05	11.1 ± 1.60 11.3 ± 1.53	-0.493	0.624	-0.12
TKT (rep)	Baseline Final	13.3 ± 1.60 14.5 ± 1.22	-3.35	0.001*	-0.86	13.5 ± 1.36 13.8 ± 1.15	-1.03	0.309	-0.26

Note. HDT: Handgrip dynamometer test, LDT: Leg dynamometer test, MBT: Medicine ball test, SLJT: Standing long jump test, HAT: Hexagon agility test, SART: Sit and reach test, MST: Multi-stage test, TPT: Target punching test, TKT: Target kick test, AR: Augmented reality: ES: Effect size, *Significantly different from baseline
to final-test values (at p < 0.05).

Table 4.
Results of the ANOVA with 2 × 2 repeated measures ([AR vs control], [baseline-test vs final-test]) on physical fitness

Variables physical fitness	Time			Group			Time * Group		
	$F_{(1.58)}$	p	η^2_p	$F_{(1.58)}$	p	η^2_p	$F_{(1.58)}$	p	η^2_p
HDT (kg)	74.7	< .001*	0.563	21.5	< .001*	0.270	52.0	< .001*	0.473
LDT (kg)	27.37	< .001*	0.321	3.66	0.061	0.059	5.03	0.029*	0.080
MBT (cm)	32.705	< .001*	0.361	4.27	0.043*	0.069	0.142	0.708	0.002
SLJT (cm)	53.3	< .001*	0.479	3.94	0.052	0.064	16.6	< .001*	0.222
HAT (s)	24.4	< .001*	0.296	3.36	0.072	0.055	41.6	< .001*	0.418
SART (cm)	97.6	< .001*	0.627	25.7	< .001*	0.307	91.8	< .001*	0.613
MST (ml/kg/min)	119	< .001*	0.672	67.0	< .001*	0.536	107	< .001*	0.648

Note. HDT: Handgrip dynamometer test, LDT: Leg dynamometer test, MBT: Medicine ball test, SLJT: Standing long jump test, HAT: Hexagon agility test, SART: Sit and reach test, MST: Multi-stage test, AR: Augmented reality, *significantly different (at p < 0.05).

Table 5.
Results of the ANOVA with 2 × 2 repeated measures ([AR vs control],[baseline-test vs final-test]) on technical performance

Variables technical performance	Time			Group			Time * Group		
	$F_{(1.58)}$	p	η^2_p	$F_{(1.58)}$	p	η^2_p	$F_{(1.58)}$	p	η^2_p
TPT (rep)	20.7	< .001*	0.263	9.26	0.004*	0.138	11.8	0.001*	0.169
TKT (rep)	42.7	< .001*	0.424	0.590	0.446	0.010	14.1	< .001*	0.195

Note. TPT: Target punching test, TKT: Target kick test, AR: Augmented reality, *Significantly different from baseline to final-test values (at p < 0.05).

Discussion

This 11-week randomized controlled study aims to investigate the effects of AR on the physical fitness and technical performance of young athletes in combat sports.

Our findings show that AR for 11 weeks is effective in improving two aspects simultaneously, namely physical fit-ness and technical performance. In addition, we observed that AR proved to have a positive effect compared to control. Based on these findings, the highlight is AR and control have a significant different characteristics and training stages. AR has a systematic training process involving tech- nology and verbal explanations from a coach to athletes re- garding knowledge and skills. AR can present animation/virtual avatar demonstrating sports movements. Meanwhile, the control group only implement traditional exercises or do not involve technology (non-AR) and focus on explanations and demonstrations from the lecturer. Therefore, the physical fitness of AR group can be betterthan the control group. This is in line with the research of Gani et al. (2023), which reported that technological tools such as VR or AR would be an appropriate way to create a training process which could be more interesting and effective compared to traditional training in improving physical fitness among athletes. Basically, training with AR can provide a deep understanding (Moreno-Guerrero et al., 2020), because it presents virtual training and direct verbal explanations by the trainer regarding the exercises contained in

AR (Petrov & Atanasova, 2020). In addition, AR technology can present and design a training environment that is realistic, interesting (Viscione & D'elia, 2019), and fun (Silva et al., 2023; O'Connor & Mahony, 2023). According to Al-Ansi et al. (2023), the presence of AR has a potential to cover the gap between traditional class and real-world experiences, thereby providing benefits for the development of athletes. On the other hand, according to Loia & Orciuoli (2019), AR was specifically created and adopted for simulations in sports activities so that it has the potentialto handle and become a solution in developing physical as-pects in athletes. Study results from Martínez-López et al. (2022), is in line with the results of this study, which re-ported that the implementation of AR program for 8 weeks in Spanish adolescents aged 12-15 years was proven to be effective in improving their physical fitness. Apart from that, other studies also reported similar results, where AR for 12 weeks was better than traditional in improving phys- ical fitness components such as strength, aerobic endur- ance, balance (Jeon & Kim, 2020). Meanwhile, Nekar et al. (2022), explained that providing information regarding ex- ercises via AR can be conducted repeatedly, which can en-courage athletes to be more enthusiastic in carrying out training and ultimately can improve their physical fitness level (Ng et al., 2019).

Other findings in this research can prove that AR also

has a positive effect on improving the technical performance of young athletes in combat sports. This is because AR pro- vides visuals punch and kick training in stages, in detail and can be played repeatedly, so that athletes can observe and analyze movements more optimally. The results of this re- search are consistent with previous research which reported that the application of AR can present a 3D animation of people performing a movement skill, so that athletes canlearn and understand the movements correctly (Liang et al., 2023). Apart from that, another advantage of AR can becarried out anywhere and at anytime, for example athletes can carry out AR training on campus with a coach or at home. Basically, AR can be a guide for athletes in learninga movement skill, even though the coach is not present in the class, the athletes can continue to practice inde- pendently. Apart from that, according to research by Loia & Orciuoli (2019), applying AR can be an effective methodto support training activities.

The uniqueness and novelty of our findings is AR through experimental research with a randomized controlled design for 11 weeks has proven that it can be an appropriate solution and utilized by coaches to improve physical fitness and technical performance among young athletes in combat sports such as pencak silat and karate.

Limitations and Future Work

Although this study has achieved its objectives, there are several limitations need to be acknowledged. First, the AR designed in this research is specifically for combat sports, namely pencak silat and karate, which is not applicable for other types of sports. Second, the limited scope of participants who only from one university in Indonesia. Thus, future research needs to improve AR design that can be usedin all types of sports. Apart from that, future research needsto involve athletes from other combat sports, such as Judo, Taekwondo, Wingcun, Tai chi, Mixed Martial arts or other types of sports.

Conclusions

Based on data and results, we highlight the importance of using AR in combat sports, because it has been proven to increase the level of physical fitness and technical performance of young athletes. This research provides benefits as information to combat sports coaches or lecturers about the positive effects related to the application of AR, so it can be applied to athletes for long-term training to achieve high achievements in combat sports, both in Pencak Silat and Karate.

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