Library Progress International
Vol.44 No. 3, July-December 2024:
P. 25473-25483

Print version ISSN 0970 1052
Online version ISSN 2320 317X

Original Article

Available online at www.bpasjournals.com

Comparative Effects of Augmented Reality and General Coordination Training on Cognitive Performance and Fatigue

Yujin Lee[1], Subin Lee[1], Dongyeop Lee[1], Jiheon Hong[1], Jinseop Kim[1], Yeongyo Nam[1], Jaeho Yu*[1]

[1]Department of Physical Therapy, Sun Moon University, Asan, Republic of Korea
* Corresponding authors: Jaeho Yu, Email: naresa@sunmoon.ac.kr

How to cite this article: Yujin Lee, Subin Lee, Dongyeop Lee, Jiheon Hong, Jinseop Kim, Yeongyo Nam, Jaeho Yu (2024) Comparative Effects of Augmented Reality and General Coordination Training on Cognitive Performance and Fatigue. *Library Progress International,* 44(3), 25473-25483

Abstract
Purpose: This study aimed to investigate the effects of augmented reality (AR)-based coordination training compared to general coordination training on cognitive function and mental fatigue in healthy adults.
Material and methods: The study involved 42 healthy university students aged 20 to 25. Participants provided informed consent and were randomly assigned to an AR training group or a general physical therapy group. The intervention consisted of a coordination exercise program conducted three times a week for 20 minutes over four weeks. Cognitive measures, including attention, concentration, coordination ability, hand coordination, and memory, were assessed pre- and post-intervention using the Slalom Bask test, throwing and catching tasks, the Cotras-Pro memory test, and the Fatigue Severity Scale (FSS). Statistical analyses, including paired t-tests and independent t-tests with significance set at $\alpha = 0.05$.
Results: After four weeks of intervention, the AR-based coordination training group exhibited significant improvements in slalom and ball throwing performance, as well as increased concentration and coordination abilities. While the AR group showed a significant increase in memory (Cotras-Pro scores), the control group did not. Independent samples t-tests confirmed significant differences in slalom and ball throwing performance between the groups. Both groups reported changes in fatigue levels, with significant differences in several sections. No significant differences in fatigue were observed between groups.
Conclusions: AR-based coordination training significantly enhances cognitive function compared to traditional physical therapy. This research suggests that AR training, utilizing real-time visual feedback, is an effective self-exercise method for cognitive improvement and is particularly beneficial in underprivileged settings.

Key words: augmented reality, coordination training, cognition, fatigue

Introductions

Movement is a fundamental activity that involves muscle contraction and the spatial movement of limbs, enabling the body to perform work. To engage in physical exercise, the body relies on energy; when energy levels deplete, fatigue sets in, affecting performance in various ways [1]. Fatigue is not merely a temporary state—it can persist, disrupting daily life and mental well-being. Without sufficient energy, the body's capacity for automatic movement, physical composure, task completion, and stress management diminishes, leading to a decline in overall performance, especially in athletic activities [2,3]. While fatigue hampers performance, physical exercise offers a unique opportunity for both physical and cognitive development. Engaging in regular exercise has been shown to improve self-esteem, lower the risk of disease, and enhance cognitive functions, such as learning and memory [3,4]. Recent research emphasizes the critical role of coordination exercises in boosting cognitive performance, including executive functions like problem-solving and decision-making [3,4,5]. Even short periods of bilateral coordination exercise can improve visuospatial perception, attention, working memory, and neurocognitive processing speed [3,5].

This growing body of research on coordination exercises highlights the value of coordination exercises in improving cognitive health. In parallel with these findings, advancements in technology have introduced augmented reality (AR) as a tool to enhance traditional exercise. AR integrates digital elements with the real world, offering users an immersive experience [6]. With improvements in hardware and software, AR has become more realistic and accessible through mobile devices, leading to its widespread use in fields such as education [7], sports, and medicine [6,8,9]. The increasing popularity of AR has sparked a surge of research exploring its potential benefits, including its application in enhancing physical exercise [10].

For instance, AR has been shown to improve learning outcomes by boosting performance and motivation [6,11]. Lin and colleagues also found that AR-based exercise programs, which provide real-time visual feedback on posture and movement, help participants correct their form and increase exercise accuracy [12]. However, AR does not come without challenges. Some studies have suggested that AR systems may place higher demands on attention, causing participants to overlook key aspects of the task or struggle with teamwork [13,14,15]. For example, Kerawalla et al. [14] observed that non-AR environments promoted more exploration and collaboration, while AR experiences were more structured and teacher-directed. Additionally, AR seemed to benefit lower-performing students more than their higher-achieving peers, raising questions about its overall effectiveness [14].

Despite the mixed findings, there is growing interest in understanding how AR can be effectively integrated into coordination training. While AR's ability to provide real-time feedback and posture correction holds promise, its impact on cognitive function remains under-researched. This study seeks to address this gap by applying AR to coordination exercises and assessing its effects on cognitive function and mental fatigue. Given that fatigue arises from energy depletion and directly impacts exercise performance [1], measuring its influence on cognitive aspects like memory and attention is crucial to understanding the full benefits of AR-based training.

By combining coordination exercises with AR, this study builds on existing research that shows physical exercise enhances cognitive functions, such as memory, attention, and concentration. Therefore, this research aimed to determine the effects of AR-based coordination training influences cognitive function and mental fatigue in healthy adults.

Material and methods

Participants

This study was conducted in the Department of Physical Therapy at Sun Moon University, involving healthy university students aged 20 to 25. A total of 42 participants were recruited, all of whom were capable of engaging in physical activity and agreed to abstain from other activities for the duration of the study. The required sample size was calculated using GPower 3.1. Participants with lower extremity pain, pre-existing musculoskeletal injury, orthopedic conditions that could limit their exercise performance, or those with recent (last 6 month) lower extremity surgery were excluded. All participants met the inclusion criteria and provided written informed consent after receiving a detailed explanation of the study's purpose and procedures. The general characteristics of the participants are presented in [Table 1].

Table 1. General characteristics

Variables	ARC group (n = 21)	TCT group (n = 21)
Gender (F/M)	11/10	10/11
Age (years)	21.14±1.10	21.10±1.09
Height (cm)	166.81±9.19	169.14±6.72
Weight (kg)	65.05±12.90	67.48±11.55

ARC = AR based Coordination Training group; TCT = Traditional Coordination Training Group

Procedure

Participants were randomly assigned to either the AR-based coordination raining group (ARC group) or the traditional coordination training group (TCT group). Outcome variables, including attention, concentration, coordination ability, hand coordination, memory, and fatigue were measured both before and after the intervention. Both groups participated in an exercise program three times a week, with each session lasting 20 minutes for a total of 4 weeks. These sessions were conducted consistently for the duration of the study, ensuring uniformity in training across all participants.

Measurement Tools and Method

All participants' height and weight were measured before the start of the experiment. Additionally, attention, concentration, coordination ability, hand coordination, and memory were assessed twice—before and after the intervention—using the Slalom Bask test, throwing and catching, and the Cotras-Pro memory test. Fatigue levels were similarly measured twice, pre- and post-intervention. To minimize the margin of error, all measurements and evaluations were conducted by the same researcher.

Attention, Concentration, and Coordination Capabilities

Attention, concentration, and coordination were evaluated using the Slalom Bask test. In this test, participants were instructed to dribble a basketball through an obstacle course as quickly as possible. The procedure began with a 5-minute warm-up, followed by verbal instructions and demonstrations according to a standardized protocol. A starting and finishing line were marked 20 meters apart on the floor, with 6 cones placed along the course at 3-meter intervals. The first cone was positioned 3 meters from the starting line. Participants dribbled the basketball with one hand, maneuvering between the cones to reach the finish line. If the ball was lost, participants retrieved it and resumed the course from where they had left off. Upon reaching the finish line, they turned and repeated the process back to the starting line.

Hand coordination ability was assessed using a ball throwing and catching test. Prior to the test, participants performed five practice throws and catches. A line was marked 3 meters from a wall, with another line drawn 1.5 meters high on the wall. Participants stood behind the floor line, throwing the ball against the wall and attempting to catch it before it hit the ground. If the ball was missed, participants retrieved it and resumed the test. The test concluded once 10 valid throws and catches were completed. The time was recorded using a stopwatch.

Memory and Fatigue Measurement

Memory was assessed using the memory section of the Cotras-Pro application. Participants completed a total of five questions, with the difficulty level increasing progressively from 1 to 6 out of 10. The test involved 7 light bulbs, where one bulb would light up for 5 seconds before turning off, and then another would light up in a different location. When the sequence reached the sixth bulb, participants were asked to recall and press the bulbs in the correct order.

Fatigue was measured using the Fatigue Severity Scale (FSS). Both the experimental and control groups completed pre- and post-surveys to evaluate and compare the impact of fatigue on exercise performance [Table 2].

Table 2. Fatigue Severity Scale

Read and circle a number.	Strongly Disagree → Strongly Agree
1. My motivation is lower when I am fatigued	1 2 3 4 5 6 7
2. Exercise brings on my fatigue	1 2 3 4 5 6 7
3. I am easily fatigued	1 2 3 4 5 6 7

4. Fatigue interferes with my physical functioning	1	2	3	4	5	6	7
5. Fatigue causes frequent problems for me.	1	2	3	4	5	6	7
6. My fatigue prevents sustained physical functioning.	1	2	3	4	5	6	7
7. Fatigue interferes with carrying out certain duties and responsibilities.	1	2	3	4	5	6	7
8. Fatigue is among my most disabling symptoms.	1	2	3	4	5	6	7
9. Fatigue interferes with my work, family, or social life.	1	2	3	4	5	6	7

Intervention Method

The participants were divided into two groups: the AR-based coordination training group (ARC group) and the traditional coordination training group (TCT group). Both groups followed the same exercise program, with the ARC group utilizing AR technology, while the control group performed the exercises based on verbal instructions from the researcher. Before the intervention, the researcher explained the training procedures and exercise protocol to all participants. Participants were advised to wear comfortable clothing and sneakers to ensure safety and accuracy during the experiment. The researcher continuously monitored the laboratory environment, ensuring consistent and safe conditions throughout the study.

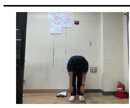
2.4.1. AR-based Coordination Training Group

The AR-based training group performed exercises using UINCARE AR equipment, which provided visual, auditory, and feedback cues. Participants followed the AR-generated protocol during their sessions. Each session included a 3-minute warm-up, a 14-minute main exercise, and a 3-minute cool-down, totaling 20 minutes. A 30-second rest period was included between exercises. This program was conducted three times a week for 4 weeks [Figure 1]. Details of the exercises are provided in [Table 3].

Traditional Coordinative Training Group

The general rowing exercise group performed exercises under verbal instructions provided by the researcher. Subjects executed the exercises based solely on the researcher's verbal guidance, following the same protocol as the UINCARE AR equipment, with auditory feedback allowing participants to adjust their exercises. The exercise regimen included a 3-minute warm-up, a 14-minute main exercise, and a 3-minute cool-down, totaling 20 minutes. A 30-second rest period was observed after each exercise, with sessions conducted three times a week for four weeks. The specifics of the exercises performed were identical to those of the ARC group.

Table 3. Exercise protocol

	Standing and bending upper body 1. The subject spreads his legs shoulder-width apart. 2. Send your arms towards the floor so that they touch your toes.
	Standing and bending knees 90 degrees 1. The subject spreads his/her legs as wide as his/her shoulder width and puts his/her hand on his/her waist. 2. Bend your knees 90 degrees, careful not to come out from your feet.
	Stand up, kick a sandbag, bend knees, and lift up 1. The subject is prepared with a sandbag on his ankle. 2. Bend your knees and lift them toward your upper body.

	a standing dumbbell / one foot back and a 45-degree bend in the knee 1. The subject prepares with dumbbells in both hands. 2. After sending one foot back, bend your knee 45 degrees and go down.
	Stand up, hold up the Madison ball, and hold it diagonally 1. The subject is prepared with a medication ball. 2. Bend your knees 90 degrees, lift the Madison ball to the side of your head, send your arms toward the opposite leg, and lower your legs.
	Standing and bending to the side of the upper body 1. The subject prepares with his legs spread shoulder-width apart and both arms next to his body. 2. Bend your body sideways so that one arm is next to your thigh.

Figure 1. AR-based coordination training

Statistical analysis

Statistical analyses were conducted using SPSS Statistics (Version 29.0.1.0). Descriptive statistics were utilized to calculate, compare, and analyze the means and standard deviations for each group. A paired t-test was employed to assess changes in attention and concentration, coordination ability, hand coordination ability, and memory before and after the intervention in both the ARC group and the TCT group. An independent t-test was used to evaluate the differences in results between the two groups. The significance level for all statistical tests was set at $p < 0.05$.

Results

This study compared the effects of AR-based coordination training (ARC) on cognitive function and mental fatigue over four weeks, comparing the traditional coordination training (TCT). A paired t-test was conducted to assess the differences within each group before and after the intervention. Results indicated a significant difference between the ARC group and the TCT group, with notable improvements: slalom and ball-throwing performance decreased, while concentration and coordination abilities increased ($p < 0.05$). In the experimental group, there was a significant enhancement in memory, as indicated by an increase in the Cotras-Pro score. Conversely, the control group did not exhibit a significant change in memory ($p > 0.05$). Following this, an independent samples t-test was performed to compare the intervention effects between the two groups.
The analysis revealed a statistically significant difference in slalom and ball-throwing performance between the two groups, with a $p < 0.05$. This suggests a meaningful difference between the averages of the ARC group and the TCT group. However, no significant difference was observed in memory performance ($p > 0.05$). Overall, the

findings indicate that AR-based coordination training is more effective for improving slalom and ball-throwing skills compared to traditional coordination training, while its effect on memory is deemed insignificant [Table 4].

Table 4. Comparison of cognitive function within and between groups

	Within roup				Between group	
	Group	Pre-test	Post-test	*t (p)*	difference	*t (p)*
Slalom Bask	ARC	23.83±9.58	15.03±6.88	5.356 (0.001*)	-8.8±7.53	-2.123 (0.043*)
	TCT	23.07±5.38	18.01±4.68	6.676 (0.001*)	-4.95±3.48	
Throwing and Catching	ARC	24.86±9.86	16.41±8.74	6.762 (0.001*)	-7.89±5.09	-2.669 (0.011*)
	TCT	25.86±13.56	22.65±12.71	2.317 (0.031*)	-3.14±6.38	
Cotras-pro memory test	ARC	2.19±1.40	3.05±1.28	-2.521 (0.020*)	0.85±1.55	2.009 (0.051)
	TCT	2.57±1.43	2.48±1.03	0.288 (0.776)	-0.09±1.51	

*p < 0.05; Mean ± Standard deviation; ARC: AR-based Coordination training; TCT: Traditional Coordination training

A t-test was also conducted to evaluate the effects of exercise using the Functional Status Scale (FSS) before and after the exercise program. The results indicated that the ARC group showed significant differences in items A2, A3, A5, A6, A7, and A9 (p < 0.05). However, no significant differences were observed in items A1, A4, and A8 (p > 0.05). In contrast, the TCT group demonstrated significant differences in items A2, A3, A5, A8, and A9 (p < .05). No significant differences were noted for items A1, A4, A6, and A7 (p > .05). The results of these analyses are summarized in [Table 5].

Table 5. Comparison of fatigue within and between groups

	Within group					Between group
	Group	Pre-test	Post-test	*t (p)*	*difference*	*t (p)*
A1	ARC	5.41±1.14	4.73±1.55	2.017 (0.127)	-.86±2.01	0.171 (0.873)
	TCT	5.33±1.27	4.48±2.08	1.957 (0.100)	-.76±1.58	
A2	ARC	4.36±1.65	3.72±1.61	1.370 (0.036*)	-.64±1.98	0.387 (0.184)
	TCT	3.57±1.63	3.15±1.88	-1.053 (0.008*)	-.42±1.76	
A3	ARC	4.77±1.63	3.82±1.44	2.768 (0.036*)	-.24±1.45	-1.397 (0.172)
	TCT	3.67±1.49	3.43±1.6	.755 (0.008*)	-.90±1.64	
A4	ARC	4.91±1.38	3.73±1.7	3.144 (0.104)	-.57±1.86	-1.013 (0.321)
	TCT	4.24±1.51	3.67±1.56	1.408 (0.240)	-1.14±1.78	
A5	ARC	3.77±1.54	3.32±1.59	1.449 (0.007*)	-.43±1.50	0.333 (0.745)
	TCT	3.71±1.52	3.29±1.68	1.307 (0.008*)	-.29±1.27	
A6	ARC	3.82±1.59	3.18±1.62	1.993 (0.006*)	-.19±1.86	-0.650 (0.523)

	TCT	3.62±1.5	3.43±1.72	.469 (0.134)	-.52±1.44	
A7	ARC	4.23±1.88	3.23±1.57	2.730 (0.014*)	-.33±1.85	-1.114 (0.279)
	TCT	3.76±1.67	3.43±1.75	.824 (0.063)	-.95±1.75	
A8	ARC	4.86±1.88	3.95±1.79	2.039(.108)	-.62±1.88	-1.246 (0.22)
	TCT	3.29±2.08	3.77±1.81	-1.208(.006*)	-.24±2.53	
A9	ARC	4±2.37	3.36±1.92	1.298(.040*)	-.67±1.46	0.079 (0.944)
	TCT	3.29±1.79	2.62±1.28	2.092(.005*)	-.62±2.36	

*$p < 0.05$; Mean ± standard deviation

A1 : My motivation is lower when I am fatigued, A2 : Exercise brings on my fatigue, A3 : I am easily fatigued, A4 : Fatigue interferes with my physical functioning, A5 : Fatigue causes frequent problems for me, A6 : My fatigue prevents sustained physical functioning, A7 : Fatigue interferes with carrying out certain duties and responsibilities, A8 : Fatigue is among my three most disabling symptoms, A9 : Fatigue interferes with my work, family, or social life

Discussion

This study investigated the effects of AR-based coordination training versus traditional coordination training on cognitive ability, focusing on coordination training. Both the ARC and TCT groups improved their slalom and ball throwing and catching records, with significant differences noted. The ARC group showed a significant improvement in memory, while the TCT group did not. Comparative analysis revealed that the ARC group outperformed the TCT group in slalom and ball throwing records, but no significant differences were found in memory assessments. Intra-group analysis of the FSS questionnaire indicated significant differences for both groups in specific items, but no differences emerged between groups.

Low- and moderate-intensity coordination exercises can enhance visuospatial perception, attentional resources, working memory, and reduce the time required for neurocognitive processing [1]. The present research confirmed that after coordination training, both groups experienced decreased slalom and ball throwing and catching records, alongside improvements in concentration and coordination abilities. Therefore, the findings suggest that cognitive function can be enhanced following coordination training. The mechanism underlying the impact of coordination exercises on cognitive function improvement is associated with the cerebellum, which is involved in attention and memory. Specifically, visuospatial attention is crucial for executing various activities and plays a central role in processing visual information and recognizing moving stimuli [12]. This research measured slalom and ball throwing and catching performance before and after training to verify improvements in visuospatial attention and coordination abilities, supporting the notion that activating these abilities contributes to cognitive function enhancement.

Contrary to the positive effects observed in attention and coordination abilities, the research indicated that coordination training did not improve memory in the general physiotherapy group. Consequently, it can be concluded that there was no difference between the averages of the experimental group utilizing AR and the general control group. It is posited that this outcome is influenced by the presence or absence of AR technology. Humans may have limited precision compared to mechanical equipment; therefore, AR can actively guide exercise, assess posture alignment, provide accurate coordinates for exercise postures, and deliver visual feedback that displays the same target [16,17]. This real-time visual feedback assists participants in modifying their subsequent exercise postures, enabling greater accuracy [6,18].

Furthermore, AR systems impose higher attention demands. Based on these research findings, this paper employs AR to provide real-time visual feedback on exercise postures to test subjects, necessitating posture corrections and enhancing accuracy, which resulted in greater memory improvements compared to the TCT group [19,20]. AR demonstrates a relationship between real-time feedback and motivational satisfaction dimensions. This indicates that utilizing positive feedback can enhance participants' emotions and increase satisfaction [20]. These findings align the fact that visual cues in multimedia education and have been shown to facilitate learning through AR [21,22].

Through this research, it was determined that the group utilizing the ARC was more effective in slalom and ball throwing and catching than the general group, while not affecting the memory improvement in the TCT group.

However, the comparison between the two groups revealed no significant difference in memory performance. This lack of difference may be attributed to the Cotras-Pro memory test's difficulty setting, which did not require a higher level of performance for healthy subjects. Consequently, the interpretation of the data was limited, leading to the conclusion that no significant difference emerged.

Several studies have shown that mental fatigue impairs selective attention, affecting concentration and increasing the number of errors, which subsequently reduces attentional performance [23,24]. In these studies, authors reported significant decreases in accuracy and increases in reaction time after mentally fatiguing tasks. This phenomenon may be explained by the interference of mental fatigue with the suppression of irrelevant information, reflecting reduced inhibition of such information and indicating that the information processing system fails to block distractions [24,25].

Although the items that differed significantly between the two groups varied, fatigue occurs due to a lack of energy, thus affecting exercise performance in diverse ways. The state of fatigue may not be temporary, and its presence can influence daily life and mental health activities. Reduced energy levels adversely affect exercise performance [2]. Fatigue-induced reductions in exercise performance resulted in low pre-measurement outcomes. By performing adjustment exercises, participants presented with improved memory, attention, and concentration, thus diminishing the impact of fatigue in these areas, leading to better post-measurement values compared to pre-measurements [25]. Significant differences were also observed in many items when comparing fatigue levels within the group. Therefore, it can be concluded that fatigue affects cognitive function, and a relationship exists between the intensity and duration of physical activity and cognitive performance.

Examining the results of fatigue within the group in this research reveals significant differences in certain items, indicating a positive effect on exercise performance as fatigue decreases. Items A2, A4, and A5 illustrate that physical function declines as fatigue increases. The fatigue process results in muscle fatigue, negatively impacting joint proprioception and impairing neuromuscular control. This muscle fatigue leads to decreased muscle activation patterns, affecting joint position sense, disrupting balance, and increasing the risk of falls [24]. Item A9 indicates that fatigue influences social life. The impact of fatigue on daily functioning emerged as a major factor in reducing quality of life. Fatigue is qualitatively, quantitatively, and intensively different from drowsiness, imposing a far greater physical and mental burden. It negatively affects the daily life, physical functions, and emotional well-being of subjects.

The findings of the present study showed significant differences in specific fatigue severity scale items, such as A2, A4, A5, and A9, within the two groups. However, no significant differences were observed between groups, suggesting that both the groups underwent the same coordination training and expanded similar metabolic resources, resulting in comparable fatigue levels. Sustained production of strength and power during exercise relies on the generation of adenosine triphosphate (ATP), which provides energy for various cellular processes involved in muscle building. ATP is produced through both non-oxidative and oxidative metabolic processes, with their relative contributions largely dictated by exercise intensity and duration [26]. In this study, both the ARC group and the TCT group maintained the same exercise intensity and duration, leading to equivalent ATP production and, consequently, similar fatigue levels.

This study has several limitations that need to be acknowledged. First, the study sample was restricted to healthy individuals in their 20s, which limits the generalizability of the findings to broader age groups and varying cognitive functions. Second, the absence of significant differences between groups in the memory assessment, cotras-pro, may be due to the difficulty setting not being calibrated for higher performance levels in healthy subjects, thereby constraining the interpretation of the results. Third, the study did not confirm the presence of depression in participants through the fatigue questionnaire, which may explain the lack of significant differences observed in specific areas. Numerous studies have established a significant association between fatigue and depression, indicating the need for further research to explore the potential impact of depressive symptoms on fatigue levels.

Conclusions

This study compared the effects of AR-based coordination training with traditional coordination training on cognitive function and mental fatigue in healthy adults. The findings indicate that AR-based coordination training led to significant improvements in all measured cognitive variables, surpassing the results of the general physical therapy group. While both groups experienced similar levels of mental fatigue, there was no significant difference between the groups. However, the ARC group demonstrated greater enhancements in cognitive function, likely due to the engaging nature of exercises supported by visual feedback. These results suggest that AR-based coordination training can serve as an effective self-exercise method, particularly in underprivileged urban and mountainous areas, and may also offer significant cognitive benefits for individuals with developmental disabilities. Future research should explore the broader applications of AR training across various populations.

Acknowledgments

The authors also express their deep gratitude to all students who participated in the study.

Conflict of interest

The authors declare that there is no conflict of interest.

References

1. Aquino M, Petrizzo J, Otto RM, Wygand J. The impact of fatigue on performance and biomechanical variables—A narrative review with prospective methodology. Biomechanics. 2022;2(4):513-24.
2. Van Cutsem J, Marcora S, De Pauw K, Bailey S, Meeusen R, Roelands B. The effects of mental fatigue on physical performance: a systematic review. Sports Medicine. 2017;47:1569-88.
3. Latino F, Cataldi S, Fischetti F. Effects of a coordinative ability training program on adolescents' cognitive functioning. Frontiers in Psychology. 2021;12:620440. https://doi.org/10.3389/fpsyg.2021.620440
4. Mandolesi L, Polverino A, Montuori S, Foti F, Ferraioli G, Sorrentino P, Sorrentino G. Effects of physical exercise on cognitive functioning and wellbeing: biological and psychological benefits. Frontiers in Psychology. 2018;9:509.
5. Kwok TC, Lam KC, Wong PS, Chau WW, Yuen KS, Ting KT, Chung EW, Li JC, Ho FK. Effectiveness of coordination exercise in improving cognitive function in older adults: a prospective study. Clinical Interventions in Aging. 2011;6:261-7.
6. Nekar DM, Kang HY, Yu JH. Improvements of physical activity performance and motivation in adult men through augmented reality approach: a randomized controlled trial. Journal of Environmental and Public Health. 2022;2022(1):3050424.
7. Bacca J, Baldiris S, Fabregat R. Insights into the factors influencing student motivation in augmented reality learning experiences in vocational education and training. Frontiers in Psychology. 2018;9:1486.
8. Dinh A, Yin AL, Estrin D, Greenwald P, Fortenko A. Augmented reality in real-time telemedicine and telementoring: scoping review. JMIR mHealth and uHealth. 2023;11:e45464.
9. Nekar DM, Lee DY, Hong JH, Kim JS, Kim SG, Seo YG, Yu JH. Effects of augmented reality game-based cognitive–motor training on restricted and repetitive behaviors and executive function in patients with autism spectrum disorder. Healthcare. 2022;10(10):1981.
10. Yu JH, Nekar DM, Kang HY, Lee JW, Oh SY. Comparison of physical activity training using augmented reality and conventional therapy on physical performance following a total knee replacement: A randomized controlled trial. Applied Sciences. 2023;13(2):894.
11. Soltani P, Morice AH. Augmented reality tools for sports education and training. Computers & Education. 2020;155:103923.
12. Lin T, Singh R, Yang Y, Nobre C, Beyer J, Smith MA, Pfister H. Towards an understanding of situated AR visualization for basketball free-throw training. In: Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems. 2021;1-13.
13. Ray S, Tawar S, Singh N, Singh G. Transition toward technological transformation: Challenges of implementing virtual reality and augmented reality in the health sector. Journal of Marine Medical Society. 2024;26(2):161-4.

14. Kerawalla L, Luckin R, Seljeflot S, Woolard A. "Making it real": exploring the potential of augmented reality for teaching primary school science. Virtual Reality. 2006;10:163-74.

15. Cerritelli F, Chiera M, Abbro M, Megale V, Esteves J, Gallace A, Manzotti A. The challenges and perspectives of the integration between virtual and augmented reality and manual therapies. Frontiers in Neurology. 2021;12:700211.

16. Etgen T, Sander D, Huntgeburth U, Poppert H, Förstl H, Bickel H. Physical activity and incident cognitive impairment in elderly persons: the INVADE study. Archives of Internal Medicine. 2010;170(2):186-93.

17. Chen K, Perera G, Fang E, Chen Fitts KB. Augmented reality (AR) posture training for manual material handling: iterative design, evaluation, and recommendation for AR interface. In: Proceedings of the Human Factors and Ergonomics Society Annual Meeting. 2022;66(1):1927-31.

18. Lee CH, Kim Y, Lee BH. Augmented reality-based postural control training improves gait function in patients with stroke: randomized controlled trial. Hong Kong Physiotherapy Journal. 2014;32(2):51-7.

19. Sanford S, Collins B, Liu M, Dewil S, Nataraj R. Investigating features in augmented visual feedback for virtual reality rehabilitation of upper-extremity function through isometric muscle control. Frontiers in Virtual Reality. 2022;3:943693.

20. Tay JL, Xie H, Sim K. Effectiveness of augmented and virtual reality-based interventions in improving knowledge, attitudes, empathy and stigma regarding people with mental illnesses—A scoping review. Journal of Personalized Medicine. 2023;13(1):112.

21. Buchner J, Buntins K, Kerres M. The impact of augmented reality on cognitive load and performance: a systematic review. Journal of Computer Assisted Learning. 2022;38(1):285-303.

22. Akçayır M, Akçayır G. Advantages and challenges associated with augmented reality for education: A systematic review of the literature. Educational Research Review. 2017;20:1-11.

23. Faber LG, Maurits NM, Lorist MM. Mental fatigue affects visual selective attention. PloS One. 2012;7(10):e48073.

24. Mortimer H, Dallaway N, Ring C. Effects of isolated and combined mental and physical fatigue on motor skill and endurance exercise performance. Psychology of Sport and Exercise. 2024;75:102720.

25. Slimani M, Znazen H, Bragazzi NL, Zguira MS, Tod D. The effect of mental fatigue on cognitive and aerobic performance in adolescent active endurance athletes: Insights from a randomized counterbalanced, cross-over trial. Journal of Clinical Medicine. 2018;7(12):510.

26. Hargreaves M. Metabolic factors in fatigue. Chinese Journal of Sports Medicine. 2006;25(4):481.

Information about the authors

Yujin Lee
foxluj@naver.com
Department of Physical Therapy, Sun Moon University
70 Sunmoon-ro 221beon-gil, Tangjeong-myeon, Asan-si,
Chungcheongnam-do, South Korea

Subin Lee
dltnqls020504@naver.com
Department of Physical Therapy, Sun Moon University
70 Sunmoon-ro 221beon-gil, Tangjeong-myeon, Asan-si,
Chungcheongnam-do, South Korea

Dongyeop Lee
https://orcid.org/ 0000-0002-2140-3277
leedy@sunmoon.ac.kr
Department of Physical Therapy, Sun Moon University
70 Sunmoon-ro 221beon-gil, Tangjeong-myeon, Asan-si,
Chungcheongnam-do, South Korea

Jiheon Hong
https://orcid.org/ 0000-0001-5232-6799
hgh1020@sunmoon.ac.kr
Department of Physical Therapy, Sun Moon University
70 Sunmoon-ro 221beon-gil, Tangjeong-myeon, Asan-si,
Chungcheongnam-do, South Korea

Jinseop Kim
https://orcid.org/ 0000-0002-1030-8063
skylove3373@sunmoon.ac.kr
Department of Physical Therapy, Sun Moon University
70 Sunmoon-ro 221beon-gil, Tangjeong-myeon, Asan-si,
Chungcheongnam-do, South Korea

Yeongyo Nam
https://orcid.org/ 0000-0001-7462-210X
nyg3583@sunmoon.ac.kr
Department of Physical Therapy, Sun Moon University
70 Sunmoon-ro 221beon-gil, Tangjeong-myeon, Asan-si,
Chungcheongnam-do, South Korea

Jaeho Yu
https://orcid.org/ 0000-0002-4714-6870
naresa@sunmoon.ac.kr
Department of Physical Therapy, Sun Moon University
70 Sunmoon-ro 221beon-gil, Tangjeong-myeon, Asan-si,
Chungcheongnam-do, South Korea