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Training sport in open-closed typology on cognitive function by controlling the role of cardiorespiratory fitness

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Abstract

Introduction: Evidence suggests that open-skill and closed-skill sports may affect cognitive functions differently. This research aimed to examine the effects of open and closed skill exercises on the executive functions (working memory, attention) of young girls, while controlling for cardiorespiratory fitness.

Materials and Methods: This study was conducted from October 2023 to January 2024 in one of the indoor sports halls of Urmia University. Using convenience sampling, 60 female undergraduate students were recruited and randomly assigned to three equal groups: control, closed skill, and open skill sports. The Wisconsin Card Sorting Test (WCST) and the N-back test were used to assess attention and working memory. Participants performed their specific training intervention for 10 weeks, with two 60-minute sessions per week. Data were analyzed using paired t-tests and ANCOVA in SPSS 26.

Results: The results showed significant improvement in working memory and attention in the open and closed skill training groups ($P< 0.05$). After controlling for the effect of cardiorespiratory fitness, the open skill group outperformed both closed skill and control groups in memory and attention ($P< 0.05$). Additionally, attention in the closed skill group was significantly better than in the control group ($P< 0.05$), while memory differences were not significant ($P> 0.05$).

Conclusion: The results suggest that open and closed skill sports can significantly improve cognitive functions; but when controlling the cardiorespiratory fitness, open skill sports appear to have a more pronounced effect.

Keywords: Attention, Cardiorespiratory fitness, Motor skills, Sports, Working memory

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Introduction

The term of cognitive function covers a domain of mental processes like attention span, concentration abilities, memory retention capacity, problem-solving strategies, and decision-making aptitude. Successful academic performance, adaptive behaviors, and everyday life functioning heavily rely on cognitive

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performance (1). On this subject, numerous investigations have been conducted over the passage of time with the aim of testing and establishing that some factors like physical activity, intelligence quotient and socioeconomic status have a high quality impact on cognitive function (2-4), lower chances of all-cause dementia and cognitive decline (5,6); while the present study was done based on development existing knowledge about the role of CardioRespiratory Fitness (CRF) as an alternative pathway and related to cognitive performance through the lifespan. The capacity of oxygen transportation by the cardiovascular system and its utilization by muscle tissue can be assessed using CRF (2). The positive impact of physical activity, notably aerobic exercise, on CRF is well-documented (2,7); studies demonstrate a significant link between higher CRF levels and improved cognitive function; However, the exact connection between physical activity and cognition is still unclear.

Research based on the variety, predictability and the execution environment divided sport activities into two types: Open Skills (OS) (e.g. racquet sports, team sports) and Close-Skills (CS) (e.g. running, swimming, cycling) (8). Open-skills are performed in a dynamic and changeable environment, while closed-skill are accomplished in a predictable and static environment (9). According to the broad transfer theory, more practice of specific skill can improve cognition for particular situations which is out of the same context (10). Formenti et al. found that children who played an OS sport showed better inhibitory control compared to inactive children and children who played CS sports (3). On the other hand, a study revealed that interference control tasks showed greater cognitive advantages for athletes involved in CS sports compared to those involved in OS sports. In contrast, problem-solving tasks showcased better results for OS sport athletes over CS sport athletes (11). It includes athletes because of long-term involvement in sports training. The implementation of sport training serves as an effective approach to mitigating cognitive function changes (12). In this regard, there is convincing proof for a complicated relationship among cognitive development and motor development (13) and has been proven that regions of the brain including the prefrontal cortex and the cerebellum overlap together in motor and cognitive control (14,15). The prefrontal cortex is normally taken into as an essential area for cognitive processing; while the cerebellum is absolutely involved in motor control. So, according evidence, activate of both area in the same time supports of the connection of both functions. According to these reasons, it can be stated that physical activity has the capacity to elicit positive reflex reactions towards cognitive stress, leading to modifications in the brain (neural plasticity) that promote improved neural activation and facilitate adjustments to novel demands and behavioral adaptations (12).

The processes underlying neurogenesis can be stimulated by an increase in CRF, subsequently promoting neuroplasticity in the hippocampus and benefiting executive functions (12,16). Further, lots of research have proven in the literature on sport-cognition, an approach frequently utilized is the cognitive component skills factor that acknowledges the valuable role of sport-training in fostering both sport-specific and overall cognitive abilities that can be applicable beyond the realm of sports to everyday life (17). On the other hand, numerous papers about CS sports with high physical fitness demands, especially CRF (e.g. running, swimming, and triathlon), have shown advantage on visual-spatial cognition like memory and attention (the Posner paradigm) (18). Also, it has been evidence about impact of the OS sports (e.g. soccer) make higher cognitive performance in total among elite athletes even in compare with CS sports (4). This indicate that the superiority of players even in cognitive advantages, cannot be entirely explained by the cardiovascular system and overshadow the cardiovascular hypothesis but it likely performs an essential role together with the cognitive aspect of exercise (cognitive stimulation hypothesis) (4).

Considering of results and suggested in previous researches (3) we examined the effect of different types of sport on cognitive factors (attention and working memory) by keeping the CRF as a mediation factor constant.

Materials and Methods

This study was conducted between October 2023 and January 2024 in one of the indoor sports halls of Urmia University. The population of this research included undergraduate female students at Urmia University. Participants were recruited through the convenience sampling by posting public announcements on university notice boards and social media.

A total of 60 eligible volunteers were selected based on inclusion criteria, and after obtaining informed consent, they were randomly assigned into three equal groups (n=20): open skill sport, closed skill sport, and control group, using a block randomization method to ensure balanced group sizes. The minimum required sample size was estimated to be 47 using G*Power version 3.1.9.2 software and to prevent sample loss due to drop-out, the final sample was set at 60 participants. The inclusion criteria included being non-smoker, having normal vision, no history of psychiatric or neurological disorders, not taking medications affecting the central nervous system, cleared for physical activity based on the Physical Activity Readiness Questionnaire (PAR-Q), and no known cardiovascular, pulmonary, metabolic, or mental disorders, and no participation in other organized sport activities. Exclusion criteria included missing more than three training sessions or unwillingness to continue participation.

The participants were matched for age and sex. The whole research lasted in 15 weeks. Pre-test information were collected in the first two weeks. Students participated in open and closed sports training for 10 weeks, twice a week and each session lasted 60 minutes. In the last 3 weeks, the variables in the post-test were measured.

Track and field training

As pervious research, subjects during the training sessions (four sessions for each skill) were learnt all skills in track and field such as: sprinting, relay, shot throw, javelin throw, and high jump with the IAAF Athletics program. Teaching sprinting and relay was done based on a series of special techniques and in a non-competitive environment. They focused on specific aspects of the sprinting techniques (i.e., starts from various positions, crouch starts, exercises which stressed the feet, leg and arm action, the stride frequency and length, acceleration runs that were used to teach the forward lean body position, etc.) and technical aspects of passing and receiving the baton in an exchange zone the preparatory exercises used to teach the sprinting technique were adventurous playful drills that included slalom, sprinting on the curb, short distance runs which emphasized the stride length and frequency, short runs clearing low hurdles and various obstacles (on a straight lane and on the curb), and acceleration runs from various starting positions. The next lesson was the long jump, which was taught with various drills, such as lateral low barrier jumps on both feet and a forward movement, jumps over low obstacles on both feet following various routes, rope jumping, stride horizontal jumps on one foot over low obstacles, placed on a circular and a straight route, hopping on each foot, hopping and stepping in various patterns, and others. Special technical exercises and drills were used to teach the long jump. They mainly emphasized the run-up approach, the run up and foot placement, and the take-off and flight (for both the stride long jump and hang style).

The same method was used to teach the scissors style high jump. Then we taught shot throw and javelin throw. Special technical exercises were applied to teach the shot put (i.e., showing how to hold the shot, pushing the shot up from a standing and a squat position, facing the throwing direction, and with the back in the throwing direction, gliding exercises, and throwing after gliding). For the javelin throw (overhead softball throw) special technical exercises were used to teach the run up strides, the standing overhead throw (i.e., the release was performed from an easy straddle position, from a stride position, where the shoulder axis was square to throwing direction) and the overhead throw after a short approach with a three and five stride pattern (18,19).

Basketball training

Twenty topics were designed for basketball training, which included skills like dribble, pass, and shoot, teaching defense and attack tactics and rules of game. The first 6 session were including basketball skills and applying them to the games. During lessons 7 to 12, we taught attack technique without the ball (i.e. supporting the ball carrier, post player, clear-out, and give-go), and with the ball (i.e. passing, catching, taking a jump shot, taking a set shot, following a shot, and making give-and-go passes) and defense skills (i.e. defending space and defending the basket). In the last 7 session (13-20), teaching focused on attack and defense tactical thinking for using in various positions (i.e. 2 vs. 2; 3 vs. 3 and 5 vs. 5) (20).

Research Instruments

A) Demographic Checklist: Participants completed a questionnaire on demographic information (age, drugs, and etc.).

B) N-Back Test: This task includes both the maintenance of cognitive information and manipulation to measure cognitive performance related to executive functions such as working memory (21). In the N-back test, a sequence of numbers appears randomly on the screen step by step as a visual stimulus. The subject has to check whether the currently presented stimulus matches the stimulus of the previous step or not. This test has two sensory aspects, visual and auditory, and the memory score (correct, incorrect answer) and reaction time in each sensory aspect are calculated separately (22). In this research, a number of visual stimuli appeared on the computer screen in sequence, and the subject had to press the "1" key if each stimulus was similar to the previous stimulus, and if there was no similarity, the "2" key on the keyboard. In this task, the person has to keep the information of only one stimulus in memory (the stimulus of a previous step). In addition, while a new stimulus replaces the previous ones, updating to the working memory rule is essential; the design of this task is such that in all stages, subjects have to respond to all stimuli. In this test, a collection of hundreds of line images is used. The N-back test has been widely used to assess working memory across diverse populations, including children with attention deficit hyperactivity disorder, elderly individuals with mild cognitive impairment, and Iranian elderly women in interventional studies (23). For example, Jalilvand et al. employed the N-back task in Iran, demonstrating its applicability in the Iranian context (24). Although formal psychometric validation of a Persian version is limited, its repeated use in Iranian research supports its practical utility in cognitive assessments.

C) Wisconsin Test (WCST): This test is one of the main evaluators for executive functions that determines the function of the frontal part of the brain such as set-shifting, flexibility, problem solving and concept formation, response transfer and the ability to overcome to the repeat and skip. In this test, four sample cards are placed on the top of the computer screen, with the shape on them (triangle, star, cross, and circle), the number of shapes (1-4), and the color of the shapes (green, blue, red, and yellow) are different from each other. A group of 64 cards is also located at the bottom of the screen, but only the top card is visible. Each card represents a state that is not repeated. Then, the subject instructed to match the cards by pressing the number written under the sample card on the keyboard. They are not given instructions on how to match the cards, but are given feedback when the matches they make are right or wrong. After placing the cards in a deck correctly, the rule changes, and the person must discover the new rule based on the feedback. The score in this test is a series of numbers, which were categorized successfully. If the subject continues with the classification principle based on the previous principle despite the change, she commits an error (25). Although detailed psychometric evaluations of the Persian version of the Wisconsin Card Sorting Test (WCST) remain limited, some studies have reported acceptable test-retest reliability for most WCST indices (ICC > 0.70) (26), and the test has also been used as a valid cognitive assessment tool in Iranian samples.

D) Cardiorespiratory fitness assessment: To measure the maximum oxygen consumption (VO2 max), a 1600-meters test walking/running were used and the VO2 max counted by following formula (27).

Vo2max=108.4 - 8.41 (min) + 0.34 (min) 2+ 0.21 (gender × age)b- 0.84 (Body Mass Index: BMI).

Results

Demographic characteristics (age, height, weight, and BMI) for each group are presented in Table 1, and the descriptive statistics of pre-test and post-test scores for the variables are reported in Table 2.

Table 1. Demographic characteristics of participants by group

Variable	Open skill (Mean ± SD)	Close skill (Mean ± SD)	Control (Mean ± SD)
Age (Year)	22.10 ± 0.69	22.25 ± 0.91	22.40 ± 1.45
Weight (kg)	65.00 ± 8.30	64.45 ± 6.80	62.95 ± 3.35
Height (cm)	165.55 ± 5.73	166.75 ± 5.15	165.95 ± 4.11
BMI	23.37 ± 2.09	23.12 ± 1.53	22.85 ± 0.82

Table 2. Descriptive statistics of pre-test and post-test scores of variables by group

Group	Variable		Pre-test Mean (SD)	Post-test Mean (SD)
Open skill	Vo_2max (ml/kg/min)		36.58 (3.02)	40.25 (3.13)
	Memory	Trues number	53.75 (7.67)	65.80 (6.12)
	Attention	Preservation error	5.45 (1.05)	3.60 (0.60)
		Cluster	23.40 (1.76)	30.15 (2.68)
Close skill	Vo_2max (ml/kg/min)		37.00 (2.48)	38.23 (2.70)
	Memory	Trues number	55.55 (8.16)	59.55 (6.74)
	Attention	Preservation error	4.95 (1.32)	4.35 (1.39)
		Cluster	25.65 (3.42)	28.10 (4.61)
Control	Vo_2max (ml/kg/min)		35.86 (1.81)	36.09 (1.90)
	Memory	Trues number	54.50 (9.02)	54.95 (9.57)
	Attention	Preservation error	4.90 (0.85)	5.15 (0.81)
		Cluster	25.50 (2.89)	25.15 (3.18)

The assumption of normality of data distribution, homogeneity of variances and homogeneity of regression slope were checked using Shapiro-Wilk test, Levene's F test, and ANCOVA test. The results showed that the assumption of normality of data distribution, homogeneity of variances, and homogeneity of regression slope were met. Therefore, we used paired t-test and ANCOVA test to analyze the data. In Table 3, the results of the paired t-test to investigate the intragroup effects are presented.

Table 3. Paired t test results

Group	Variable		Mean difference (Pre-test – Post-test)	SD	t	df	P
Open skill	Vo_2max		3.68	1.16	14.145	19	0.001*
	Memory	Trues number	12.05	4.99	10.778	19	0.001*
	Attention	Preservation error	-1.85	1.27	-6.525	19	0.001*
		Cluster	6.75	2.38	12.676	19	0.019*
Close skill	Vo_2max		1.22	0.57	9.662	19	0.001*
	Memory	Trues number	4.00	5.80	3.082	19	0.006*
	Attention	Preservation error	-0.60	1.23	-2.179	19	0.042*
		Cluster	2.45	3.20	3.421	19	0.003*
Control	Vo_2max		0.22	0.80	1.240	19	0.230
	Memory	Trues number	0.45	3.25	0.619	19	0.543
	Attention	Preservation error	0.25	0.55	2.032	19	0.056
		Cluster	-0.35	4.11	0.381	19	0.707

*$P< 0.05$

The results of the paired t-test to investigate the intra-group effects showed that Vo2max, memory (trues number) and attention (preservation error, cluster) in the open skill and closed skill groups improved significantly from pre-test to post-test ($P< 0.05$), but the changes in the control group were not significant ($P> 0.05$) (Table 2). Table 4 shows the ANCOVA test results to compare the post-test scores.

Table 4. ANCOVA test results

Variable		Source	Sum of squares	df	Mean square	F	P	Partial Eta
Memory	Trues number	Vo2max	8.817	1	8.817	0.453	0.453	0.008
		Pretest	2173.018	1	2173.018	111.373	0.001*	0.670
		Group	846.664	2	423.332	21.768	0.001*	0.442
		Error	1069.619	55	19.448			
Attention	Preservation error	Vo2max	0.204	1	0.204	0.261	0.612	0.005
		Pretest	11.223	1	11.223	14.335	0.001*	0.207
		Group	17.913	2	8.956	11.440	0.001*	0.294
		Error	43.058	55	0.783			
	Cluster	Vo2max	1.349	1	1.349	0.133	0.717	0.002
		Pretest	172.358	1	172.358	16.934	0.001*	0.234
		Group	249.067	2	124.533	12.235	0.001*	0.308
		Error	559.812	55	10.178			

*$P< 0.05$

The ANOVA test results showed a significant difference between the post-test scores of memory (trues number) and attention (preservation error, cluster) in the groups ($P<$ 0.05) after controlling the effect of pre-test and vo2max. Therefore, Bonferroni's post hoc test was used to compare two groups (Table 5).

Table 5. Bonferroni post hoc test results

Variable		Group I	Group J	Mean difference (I-J)	P
Memory	Trues number	Open skill	Close skill	7.292	0.001*
			Control	10.784	0.001*
		Close skill	Control	3.492	0.064
Attention	Preservation error	Open skill	Close skill	-0.912	0.012*
			Control	-1.683	0.001*
		Close skill	Control	-0.771	0.036*
	Cluster	Open skill	Close skill	3.354	0.011*
			Control	6.083	0.001*
		Close skill	Control	2.728	0.040*

*$P<$ 0.05

The results showed that after controlling for vo2max in memory (true number) and attention (preservation error, cluster), the open skill group was significantly better than the closed skill group and control ($P<$ 0.05). Also, the attention of the closed skill group was significantly better than the control group, but no significant difference was observed between the memory of the closed skill group and the control group ($P>$ 0.05).

Discussion

The findings of the present study demonstrated that both Open-Skill (OS) and Closed-Skill (CS) sports groups showed significant improvements in attention and working memory scores in the post-test compared to the pre-test. After controlling for cardiorespiratory fitness, attention scores in the OS group were significantly higher than those in the CS and control groups, and the CS group also outperformed the control group. These results support the hypothesis that the nature of the sport type, particularly the cognitive demands imposed during training and performance plays an important role in enhancing executive functions such as attention and working memory.

This finding is consistent with studies reporting that OS sports, due to their unpredictable environments, promote cognitive processes including response inhibition, attention switching, and decision-making (28-30). Heilmann et al. conducted a systematic review and meta-analysis to examine the effects of OS sports (such as basketball, soccer, handball, and tennis) compared to CS sports (such as swimming, track and field, and gymnastics) on executive functions. The results of this analysis, which included 19 studies and 1,798 participants from different countries, showed that OS sports had a greater effect on components such as cognitive control, response inhibition, mental flexibility, and working memory than CS sports. These findings suggest that the unpredictable and complex nature of OS sports is a better stimulus for enhancing the brain's executive functions (28). Also, a systematic review by Lai et al. also showed that in all age groups, especially children and adolescents, OS sports promote focused attention and cognitive flexibility more than CS sports (29). Koch and Krenn compared executive functions (e.g., working memory, cognitive flexibility, and response inhibition) among 75 elite athletes (45 men and 30 women) in two groups: OS sports (e.g., soccer, basketball, tennis) and CS sports (e.g., swimming, gymnastics, track and field). The findings showed that OS athletes performed better in working memory and cognitive flexibility than the CS group. Interestingly, CS athletes who participated more in OS sports during childhood and adolescence also scored higher on cognitive performance. These results emphasize the important role of cognitive experiences in dynamic sports in enhancing executive functions (30). In these sports, athletes must continuously adapt to changing external stimuli, requiring rapid sensory processing and motor response. For instance, in basketball—an OS sport players must monitor teammates, opponents, ball position, and timing cues simultaneously (31), which places high demands on selective attention and spatial working memory.

Compared to CS sports, which involve repetitive and predictable movements (e.g., swimming or track), OS sports require more frequent engagement of prefrontal cortical areas linked to cognitive control and flexibility (32,33). The results of the current study align with Koch and Krenn who found that elite OS athletes outperformed CS athletes in tasks assessing working memory and cognitive flexibility. These cognitive demands likely explain why OS participants in our study showed greater improvements in both attention and working memory compared to the other groups (30).

In addition, the higher working memory scores in the OS group even after adjusting for fitness support findings by Pourghavami and Wang et al. emphasized the need for continuous mental updating and rapid decision-making in OS athletes (27,31). Basketball, in particular, requires integrating multiple streams of dynamic visual information while planning movements, which can enhance working memory capacity over time.

Neurobiological evidence further supports the cognitive benefits of physical activity. Exercise has been associated with increased hippocampal volume (34), enhanced gray matter in prefrontal areas (35), and increased levels of brain-derived neurotrophic factor, which facilitates neuroplasticity and learning (36,37). Marvel et al. also showed that even in the absence of overt movement, motor planning regions are engaged during working memory tasks, suggesting a neural overlap that might be reinforced through sport (38).

Despite these positive findings, not all studies agree. For example, Russo et al. reported no significant differences in working memory among OS, CS, and control groups (39). Russo et al. studied the effect of exercise type on cognitive functions (visual working memory, reasoning, and visual search) in 95 adults (33 women and 62 men). The subjects included 37 open-skill athletes, 32 closed-skill athletes, and 26 inactive individuals. The athletes were at a semi-professional to professional level. The results showed that open-skill athletes performed better than the other groups in visual search, but no significant differences were observed in working memory and reasoning. Years of training were controlled as a covariate to obtain more accurate results. Such inconsistencies may stem from variations in measurement tools (e.g., visual vs. verbal working memory), participant age, or level of expertise (39). Our sample consisted of amateur young athletes, while some studies have focused on elite or older athletes (40), who may demonstrate more pronounced cognitive differences due to long-term training effects. It is also noteworthy that in our study, the CS group did not significantly differ from the control group in working memory, although they did in attention. This could be due to the lower cognitive demands of CS sports or because controlling for cardiorespiratory fitness removed a potential source of variance, as several studies have shown a positive correlation between fitness level and working memory performance (41).

Additionally, other unmeasured factors such as engagement in cognitively stimulating activities outside of sport (e.g., video games or musical training), socioeconomic status, or personality traits could act as confounders. Therefore, future studies should more rigorously control for such variables to better isolate the effects of sport type on cognition.

Conclusion

In conclusion, participation in open-skill sports results in greater improvements in attention and working memory among young females, independent of cardiorespiratory fitness levels. These findings emphasize the importance of cognitive demands inherent in sport types and their influence on executive functions. Such insights can guide physical education programs to incorporate diverse sport activities that foster cognitive development. Future studies should employ longitudinal and neuroimaging approaches to further elucidate these effects across different age groups.

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Conflict of Interest

The authors declare no conflict of interests.

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Ethical Considerations

This study was approved by the Ethical Committee of Biomedical Research at the Institute of Physical Education and Sports Sciences, Urmia University. Written informed consent was obtained from all participants prior to their inclusion in the study.

Code of Ethics
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Authors' Contributions

R.K: Conceptualization, methodology, supervision, investigation, writing – original draft, writing – review and editing, and project administration

H.M: Data curation, methodology, resources, and investigation

S.E : Statistical analysis, validation, writing – review and editing

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