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Comparison of Hot and Cool Executive Functions of the Brain in Young Athletes with Similar Cognitive Demands across Open and Closed Skills

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Original Article

Abstract

Introduction: Executive functions play an important role in shaping the future-oriented cognitive skills of adolescents, both under relatively abstract and non-emotional conditions (cool executive function) and emotionally salient, motivational contexts (hot executive function). Empirical evidence shows that there is a relationship between executive function, exercise, and physical activity. However, all forms of physical activity do not affect cognition in the same way. The present study aims to compare the effect of exercise with similar cognitive demands on the executive functions of intermediate-level athletes.

Materials and Methods: A total of 100 female intermediate-level athletes participating in club-level shooting sports (n = 50 fixed targets, n = 50 flying targets), aged 13–18 years, were selected from shooting clubs in Yazd Province, Iran, using a convenience sampling method. To measure cold executive functions, N-back task, the modified Flanker task, and Wisconsin Card Sorting Test (WCST) were used, while the Iowa Gambling Task (IGT) was employed to assess hot executive functions. Then the data analysis was done according to the results of the tests.

Results: A significant difference was observed in mean response inhibition scores between the congruent and incongruent conditions in the open-skill versus closed-skill athlete groups, favoring the open-skill group ($P < 0.001$). The results indicated no significant differences between the open-skill and closed-skill groups across several metrics: total score, net score, and response time for hot executive functions; outcome and reaction time for working memory; and the number of categories and perseverative errors for cognitive flexibility ($P > 0.05$).

Conclusion: The study findings confirm the far transfer hypothesis, suggesting that the division of sports into open- and closed-skill disciplines may not be a suitable criterion for measuring the impact of the environment on executive functions. An open-skill environment characterized by moderate cognitive demands can exert an influence on executive functioning comparable to that of a closed-skill environment with similar cognitive demands.

Keywords: Executive function; Open skill; Closed skill; Athlete

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Introduction

Physical exercise and athletic training promote the development and maintenance of cognitive skills in humans (1-4). This hypothesis is further supported by empirical evidence from various sports, including soccer (5, 6), tennis (7), basketball (8), and volleyball (9). However, it is well-established that not all forms of physical activity exert a uniform influence on cognition (10). Based on environmental demands and the degree of variability in movement execution, athletic activities are categorized along a continuum ranging from closed-skill to open-skill environments (Figure 1) (11).

Closed-skill activities are characterized by relatively stable environments and repetitive motor patterns, as seen in sports such as swimming or walking (12).

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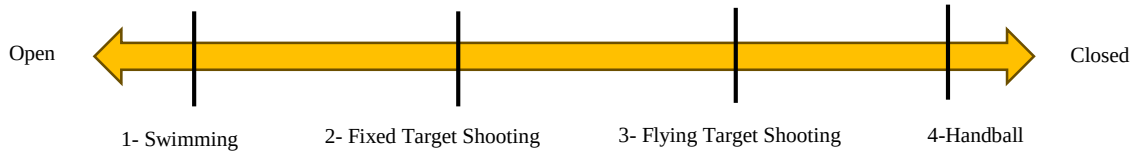


Figure 1. Horizontal continuum for classifying sports into open and closed sports skills

Conversely, open-skill sports—such as handball, soccer, fencing, and table tennis—require continuous adaptation to unpredictable environmental conditions and rapidly changing situations (5, 12, 13). Consequently, open-skill performance necessitates a high level of visual attention, rapid and flexible decision-making, and agile motor responses (14, 15). Due to the inherent stability of their environment, closed-skill sports typically impose fewer cognitive demands on athletes, as motor units operate within a predictable framework, reducing the need for constant environmental adaptation in open-skill disciplines (16). Environmental conditions and movement requirements can significantly modulate participants' executive functions. According to the Broad Transfer Hypothesis (17), cognitive gains achieved during the practice of a specific sport are transferred to untrained cognitive tasks. This premise suggests that athletes in open-skill sports, who are consistently exposed to complex cognitive stimuli, should exhibit superior performance in related cognitive functions compared to those in closed-skill environments (13, 18-20). A substantial body of research has demonstrated a positive correlation between open-skill athletic training and enhanced executive performance (21, 22). Specifically, comparative studies examining executive functions (EFs) across open- and closed-skill sports have consistently reported that open-skill disciplines exert a more profound influence on the development of EFs than their closed-skill counterparts (21-27). However, this binary classification fails to account for the variance in cognitive demands within each category, potentially overlooking sports with high cognitive requirements regardless of their skill type. There remains an ongoing controversy regarding the complex interplay between diverse athletic requirements and executive functions, particularly over whether the cognitive benefits are reserved exclusively for open-skill environments. Furthermore, there is a paucity of research concerning the relationship between EFs and closed-skill sports, as well as the underlying mechanisms that may drive cognitive enhancement in these disciplines (28). To date, it remains unclear whether closed-skill activities with high cognitive demands can elicit improvements comparable to those observed in open-skill sports. Consequently, the existing literature is insufficient in elucidating the extent to which cognitive gains derived from specialized athletic training generalize to other cognitive domains (29-31).

While a vast amount of research has examined executive functions (EFs) in adult populations (10, 32), there is a notable dearth of comparative studies focusing on open- and closed-skill sports among younger cohorts, specifically children and adolescents. This gap is particularly concerning given that the period from ages 3 to 18 is critical for the maturation and structural formation of EFs (30). According to Poon (33), the developmental trajectories of EFs during adolescence are non-uniform, with "hot" and "cool" executive functions following distinct paths. Specifically, hot EF exhibits a slower rate of development, lagging behind the more rapid maturation of cool EF (34). Such a developmental dissociation underscores the need to investigate both hot and cool EFs during this formative period to understand better how different athletic environments may influence these divergent cognitive pathways.

Previous comparative research has primarily contrasted open-skill sports, characterized by high cognitive demands and dynamic environments, with closed-skill sports, which involve lower cognitive requirements. However, these studies often lack granular descriptions and nuanced interpretations of the specific athletic contexts involved (29-31). Regarding cool executive functions—defined by researchers as the triad of working memory, inhibition, and cognitive flexibility (35)—a wealth of evidence suggests that both athletic proficiency and sport type exert positive influences, with small-to-medium effect sizes, on various non-athletic cognitive subdomains. Conversely, there is a profound paucity of data concerning hot executive functions, despite their critical role in scenarios requiring emotional regulation and decision-making under affective pressure (36, 37). While qualitative analyses indicate that open-skill athletes generally outperform closed-skill athletes in executive tasks, the precise nature of this advantage remains underspecified.

Evidence from 11 out of 19 reviewed studies indicates a positive effect of open-skill sports on executive performance. However, these findings

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primarily stem from comparisons between high-demand open-skill sports—such as tennis, table tennis, and badminton (categorized as Level 4 on the open-closed continuum), which necessitate high cognitive engagement, dynamic environments, and unpredictable motor patterns—and low-demand closed-skill activities, such as swimming or running (categorized as Level 1), which require minimal cognitive processing. Given this stark contrast in cognitive load, it is logically expected that such analyses would yield significant differences in favor of open-skill sports. According to the Broad Transfer Hypothesis, when comparing sports situated toward the center of the continuum (Levels 2 and 3), the observed differences should be considerably smaller, as these disciplines impose similar cognitive demands and cultivate homogeneous cognitive skills. This suggests that the specific cognitive requirements of a sport must be rigorously accounted for when interpreting the effects of open versus closed skills on cognition (30). Consequently, a simplistic binary classification of sports into "open" or "closed" is insufficient for a comprehensive understanding of their impact on cognitive functions (30). In this regard, Kern et al. (21) proposed that future research should incorporate the varying degrees of cognitive demands within both open and closed skills. To further validate the Broad Transfer Hypothesis, future studies must categorize athletic modalities by their actual cognitive load, as a rudimentary distinction between open and closed skills is inadequate for drawing deeper theoretical inferences (30).

In summary, the present study was designed to address the critical gaps identified in the existing literature. While previous research has largely overlooked the nuanced distinctions between hot and cool executive functions (EFs) and focused predominantly on adult populations, this study specifically targets adolescents aged 13 to 18—a pivotal developmental window for the maturation of EFs. Furthermore, whereas prior studies have frequently contrasted the extremes of the open-closed skill continuum, the current research focuses exclusively on semi-professional shooters (comparing static-target and clay-target disciplines). These disciplines provide a unique experimental model, as they possess closely aligned yet distinct cognitive requirements from the perspective of open and closed skill sets. Consequently, the primary objective of this study is to compare the hot and cool executive functions of adolescent athletes who operate within similar cognitive demand profiles across the open-closed skill divide.

Materials and Methods

Ethics and Study Design: This study was conducted in accordance with the ethical guidelines of the Islamic Azad University, Isfahan-Khorasgan branch, and received the corresponding ethical approval code. The research employed a quasi-experimental design.

The required sample size was determined using G*Power software (Freeware, version 3.1.9.7, Released March 17, 2020, University of Düsseldorf, Düsseldorf, Germany). Based on an effect size of 0.9, an alpha level of 0.05, and a power of 0.9, the minimum required sample size was calculated to be 41 participants per group. To account for potential attrition, the sample size was increased to 50 participants per group. A total of 100 female semi-professional shooters (50 in static target and 50 in clay target disciplines), aged 13 to 18 years, were recruited via convenience sampling from sports clubs in Yazd province. Eligible participants were required to be active members of their respective teams and have competed in at least three official provincial competitions. During an initial briefing session, the study objectives, procedures, and experimental conditions were thoroughly explained to the participants and their parents, and all queries were addressed. Written informed consent was obtained from the parents of all participants. Additionally, verbal assent and a willingness to participate were secured from the adolescents themselves prior to their inclusion in the study.

Instruments

To evaluate the participants' cognitive profiles, a battery of validated neuropsychological tests was employed. Cool executive functions (EFs) were assessed using the N-back task (to measure working memory), the Modified Flanker Task (to assess inhibitory control), and the Wisconsin Card Sorting Test (WCST; to evaluate cognitive flexibility). Furthermore, hot executive functions—specifically decision-making under emotional uncertainty—were measured using the Iowa Gambling Task (IGT). Detailed descriptions of each instrument are provided below.

A: N-Back Task: The N-back task is one of the most widely recognized and validated computerized paradigms for assessing working memory. Because this task requires both the maintenance and manipulation of cognitive information, it is considered an ideal measure of working memory performance. Specifically, the N-back task heavily engages the Central Executive System during processing. In the present study, the Persian computerized version developed by the Sina Institute for Research in Behavioral and Cognitive Sciences (38, 39) was

employed and standardized by Khodadadi, Nazar-boland, and Amani (40). Performance was evaluated based on accuracy scores and reaction times, both of which were automatically calculated by the software.

During the task, a sequence of visual stimuli is presented on the screen. Participants are required to press the designated key (e.g., the '?' key) if the current stimulus matches the one presented n steps back, or the 'z' key if there is no match. The cognitive demand increases as n increases, thereby increasing the task's difficulty. Each trial consists of 100 stimuli, and the total duration, including the practice phase, is approximately 3 minutes.

B: Modified Flanker Task: In cognitive psychology, the Flanker Task is a well-established paradigm for assessing inhibitory control, specifically the ability to suppress irrelevant stimulus features to execute a goal-directed response. This task evaluates selective attention, information processing speed, and cool executive function by measuring accuracy and reaction times across congruent, incongruent, and neutral trials. In the present study, we employed the Persian computerized version of the Modified Flanker Task developed by the Sina Institute for Research in Behavioral Cognitive Sciences (41, 42) and standardized by Khodadi, Barzegar, and Amani (43).

The task consists of white stimuli (size 34) presented on a black background for 200 ms. Stimuli appear in three configurations: (1) congruent (e.g., <<<<< or >>>>>, (2) incongruent (e.g., <<><< or >> < >>), and (3) neutral (e.g., --<-- or -->--). The inter-stimulus interval (ISI) varies between 1,000 and 1,600 ms randomly. Participants are instructed to respond as quickly and accurately as possible to the direction of the central arrow, while ignoring the flanking distractors (44). For instance, a response to the right is correct for <<<<<, while a response to the left is correct for both <<><< and -->--. Performance is quantified by accuracy (correct/incorrect responses on congruent and incongruent trials), reaction time, and the interference score, calculated as the difference in accuracy between congruent and incongruent trials.

C: Wisconsin Card Sorting Test (WCST): The WCST is a widely utilized neuropsychological instrument for assessing cognitive flexibility and cool executive functions (45). In this study, we employed the Persian computerized version developed by the Sina Institute for Research in Behavioral and Cognitive Sciences, which was standardized by Khodadayi, Shahgholian, and Amani (46). The test typically takes 2.5 to 10 minutes to administer, depending on the participant's response speed, and consists of 64 cards. Each card features four shapes (triangle, star, cross, and circle) in four colors (blue, yellow, green, and red). Participants are required to sort the cards based on a specific underlying rule—either shape, color, or number (47).

Following each trial, immediate written feedback ("correct" or "incorrect") is provided at the bottom of the screen. Once a participant completes six consecutive correct sorts, the sorting rule changes without prior notification. The participant must then identify the new rule through trial and error, guided by the provided feedback. The test concludes when the participant completes six sets (each consisting of six consecutive correct responses) or reaches the maximum of 64 trials. The number of completed categories quantifies performance, the number of perseverative errors (defined as the failure to shift to a new rule despite feedback, continuing to sort by a previous rule), and the number of non-perseverative errors (48, 49). The reliability of this Persian version has been reported to range from 75% to 92% (50, 51), with favorable validity indices observed in the Iranian population (52).

D: Iowa Gambling Task (IGT): The Iowa Gambling Task is a specialized paradigm designed to evaluate decision-making processes, particularly within the domain of "hot" executive functions (53). As a measure of value-based decision-making, the IGT was first introduced by Bechara et al. (1994) to examine how individuals navigate financial choices between high-gain/high-risk and low-gain/low-risk options (53). The task relies on a reward-penalty learning mechanism, often referred to as knowledge-based learning, which serves as the foundation for this category of assessments (54, 55). In the present study, the Persian computerized version developed by the Sina Institute for Research in Behavioral and Cognitive Sciences and standardized by Khodadi, Saed, and Amani (53) was employed.

In this task, participants are presented with four decks (A, B, C, and D). Decks A and B offer high immediate rewards but entail severe long-term losses, making them "disadvantageous" decks. Specifically, Deck A provides larger rewards but frequent losses, while Deck B offers slightly lower rewards with less frequent but more severe losses; both eventually lead to a net loss. Conversely, Decks C and D provide smaller immediate rewards but have significantly lower losses, making them "advantageous" in the long run. Participants must strategize their choices to maximize their total gain. Healthy individuals typically learn to prefer the advantageous decks (C and D) due to their lower penalty profiles. Performance is quantified by the software based on the net score, total score, and reaction time. Prior research has demonstrated a strong correlation between IGT performance and broader

executive function profiles (56).

Procedure

Informed Consent and Group Allocation: The study commenced with a briefing session attended by the participants and their parents, during which the research objectives, experimental conditions, and procedures were explained in detail. Written informed consent was obtained from the parents, and verbal assent was secured from the participants. The shooters were categorized into two groups based on their discipline: static target shooters were assigned to the closed-skill group, and clay target shooters to the open-skill group.

Testing Protocol: To eliminate potential carryover effects and minimize interference between assessments, the N-back, Modified Flanker, WCST, and IGT were administered in separate sessions in a quiet, well-lit environment. Prior to the formal administration of the N-back and Modified Flanker tasks, participants completed a practice phase to ensure familiarity with the computerized interface. In contrast, the WCST and IGT were administered without a preliminary practice phase. Following the completion of all assessments, the collected data were subjected to statistical analysis based on the test results.

Results

The mean age was 15.86 ± 0.75 years in the open-skill athletes group and 15.76 ± 0.77 years in the closed-skill athletes group. The mean sport experience was 3.38 ± 1.12 years in the open-skill group and 2.8 ± 1.1 years in the closed-skill group. According to the independent-samples t-test, no significant difference was observed between the two groups in mean age or sports experience ($p > 0.05$).

The descriptive findings of the study variables, separated by group, are presented in Table 1.

As shown in Table 1, the mean scores of hot and cold executive functions differ descriptively between the open-skill and closed-skill athlete groups. The statistical significance of these differences is examined below.

In the present study, multivariate analysis of variance (MANOVA) was employed for the inferential analysis of the results, as it allows the researcher to examine differences in the mean scores of the study variables across groups. Accordingly, it was necessary to verify the assumptions required for the application of parametric tests. The principal assumptions of the analysis of variance were therefore examined, namely: (1) normality of the distribution of scores; (2) homogeneity of variances, assessed using Levene's test; and (3) equality of the variance–covariance matrices, assessed using Box's M test. The results were as follows. The skewness and kurtosis values for all study variables fell within ±1.98, indicating that the data were normally distributed.

Table 1. Descriptive statistics of the research variables across open-skill and closed-skill athletic groups

Test	Variable	Group	Mean	SD
Flanker test — Response inhibition (cold EF)	Interference score	Open-skill	−8.6	14.38
		Closed-skill	−13.22	18.07
	Interference time	Open-skill	40.38	25.38
		Closed-skill	19.58	15.97
	Congruent responses	Open-skill	110.96	20.88
		Closed-skill	92.64	23.14
	Incongruent responses	Open-skill	103.28	26.33
		Closed-skill	79.28	20.39
	Congruent reaction time	Open-skill	511.7	95.39
		Closed-skill	525.32	112.15
	Incongruent reaction time	Open-skill	555.62	93.71
		Closed-skill	545.38	138.47
Iowa Gambling Task — Decision making (hot EF)	Total score	Open-skill	1736.5	810.1
		Closed-skill	1767.5	991.7
	Net score	Open-skill	5.1	28.53
		Closed-skill	10.66	61.16
	Time	Open-skill	224.28	62.08
		Closed-skill	235.46	61.88
N-back — Working memory (cold EF)	Score	Open-skill	94.28	26.63
		Closed-skill	93.8	26.82
	Time	Open-skill	596.98	135.54
		Closed-skill	603.7	150.85
Wisconsin Card Sorting Test — Cognitive flexibility (cold EF)	Categories completed	Open-skill	3.24	1.82
		Closed-skill	3.25	2.05
	Perseverative errors	Open-skill	5.5	3.92
		Closed-skill	6.9	5.06

Table 2. Multivariate Analysis of Variance (MANOVA) results comparing hot and cool executive functions between open-skill and closed-skill athletic groups

Variable	Wilks' Lambda	F	Hypothesis df	Error df	P	Effect size (η^2)	Statistical power
Response inhibition (cold)	0.883	2.06	6	93	0.021	0.117	0.855
Iowa Gambling Task — decision making (hot)	0.991	0.293	3	96	0.83	0.009	0.105
Working memory (cold)	0.999	0.028	2	97	0.972	0.001	0.054
Cognitive flexibility (cold)	0.947	2.72	2	97	0.117	0.053	0.326

Likewise, the results of the Kolmogorov–Smirnov test for all study variables indicated that the null hypothesis of normality of the score distribution was retained in both the open-skill and closed-skill athlete groups; that is, normality was not rejected, the distributions were consistent with the population, and the observed skewness and kurtosis were attributable to chance (all significance levels were greater than 0.05). Levene's assumption of equality of variances across groups was likewise not rejected for any of the study variables (significance levels greater than 0.05). In addition, the assumption of equality of covariances—that is, of the relationships among the dependent variables—was not rejected (significance level greater than 0.05). Multivariate analysis of variance was used to examine differences in the mean scores of the study variables between the two groups. In other words, the scores for each of the hot and cold executive functions were examined in separate analyses, and the results are summarized in Table 2.

The results in the first row of Table 2 showed that the mean response inhibition scores differed significantly between the two groups of athletes with open and closed skills ($F = 2.06$, $P = 0.021$). The results indicated that 11.7% of the individual differences in response inhibition were attributable to the difference between the two groups. However, based on the findings presented in the second row of Table 2, the mean hot executive function scores did not differ significantly between the two groups of athletes with open and closed skills ($P > 0.05$). The results showed that only 0.9% of the individual differences in hot executive functions were attributable to the difference between the two groups, which is a negligible and non-significant amount. Likewise, based on the results in the third row of Table 2, the mean working memory scores did not differ significantly between the two groups of athletes with open and closed skills ($P > 0.05$). The results showed that only 0.1% of the individual differences in working memory functions were attributable to differences between the two groups, a negligible and non-significant amount. Similarly, based on the results in the fourth row of Table 2, the mean cognitive flexibility scores did not differ significantly between the two groups of athletes with open and closed skills ($P > 0.05$). The results showed that only 5.3% of the individual differences in (cold) cognitive flexibility were attributable to the difference between the two groups, which is a negligible and non-significant amount.

The results of the univariate analysis of variance examining the differences between the two groups on each study variable are presented in Table 3.

Table 3. Results of Univariate Analysis of Variance for Examining and Comparing Groups on Individual Hot and Cold Executive Functions

Variable	Sum of Squares	df	Mean Square	F	P	Effect Size	Statistical Power
Response Inhibition (Cold)							
Interference Score	533.61	1	533.61	2.00	0.16	0.02	0.288
Interference Time	10816	1	10816	1.44	0.233	0.014	0.221
Congruent Response	8390.56	1	8390.56	8.19	0.005	0.077	0.809
Incongruent Response	14400	1	14400	12.39	0.001	0.112	0.939
Congruent RT	4637.61	1	4637.61	0.428	0.515	0.004	0.099
Incongruent RT	2621.44	1	2621.44	0.188	0.666	0.002	0.071
Hot Executive Function							
Total Score	80348.075	1	80348.075	0.029	0.864	0.001	0.053
Net Score	223156.72	1	223156.72	0.339	0.562	0.003	0.089
Time	376490.5	1	376490.5	0.813	0.369	0.008	0.145
Working Memory (Cold)							
Score	5.76	1	5.76	0.008	0.929	0.001	0.051
Time	1128.96	1	1128.96	0.055	0.815	0.001	0.056
Cognitive Flexibility (Cold)							
Categories	0.001	1	0.001	0.001	0.999	0.001	0.05
Perseverative Errors	49	1	49	2.39	0.126	0.024	0.334

The results in Table 3 showed that the difference in mean congruent and incongruent response scores of response inhibition between the two groups of athletes with open and closed skills was significant ($p < 0.01$). The effect size of group membership, or the difference between the two groups for congruent responses, was 7.7%, and for incongruent responses was 11.2%. According to the mean scores in Table 1, both congruent and incongruent response dimensions in the group of athletes with open skills were significantly higher than in the group of athletes with closed skills. However, the results showed that all three components of total score, net score, and time in hot executive function, as well as score and time in working memory (cold), and the two dimensions of categories and perseverative errors in cognitive flexibility (cold) did not show significant differences between the two groups of athletes with open and closed skills ($p > 0.05$).

Discussion

The present study aimed to examine differences in executive function between semi-skilled athletes performing open and closed skills with comparable cognitive demands. The theory of far transfer of skills proposes that practice in one domain may improve the relevant cognitive structures and even those underlying untrained tasks (17). In this approach, it is assumed that cognitive abilities acquired through practice of a particular sport transfer to untrained functions and tasks (21). Considering the cognitive demands of open and closed skills, as well as the training characteristics of semi-skilled athletes, differences in executive function are to be expected (23).

In the present study, no significant difference in working memory was observed between shooters of stationary and flying targets. These results appear to contradict the findings of studies (23, 57), which reported results in favor of open skills, while being consistent with the findings of studies (21, 58). Athletes in strategic sports (open skills) are better able to maintain information in mind and actively replace previously held information, whereas athletes in static sports (closed skills) are not (11). We expected athletes performing flying-target skills to obtain higher working memory scores, since they must continually replace prior information with the position of new flying targets. Although at the descriptive level both accuracy and reaction time on the N-back task favored the open-skill group, the differences were not statistically significant.

Regarding cognitive flexibility, no significant difference was found between the two groups. These results appear to contradict the findings of studies (23, 58, 59) and to be consistent with those of studies (20, 60, 61). It should nevertheless be emphasized that previous studies sampled athletes with differing levels of experience and expertise and across different age ranges, which limits the comparability of our study. The discrepancy between our sample and previous research on the selection of open- and closed-skill sports may have contributed to these results. The high decision-making speed required in open sport skills, for example initiating a counterattack after losing possession in football or basketball, or responding to an external stimulus, demands cognitive flexibility, which is essentially not required in closed-skill sports, because changes in the environment during competition do not occur rapidly and are not unpredictable (23). Previous studies have focused on sports with high cognitive demands, such as handball and basketball, in which individual positioning and tactical behavior in relation to teammates and opponents make working memory and cognitive flexibility fundamental cognitive skills (62). That we found no significant difference in cognitive flexibility between the open- and closed-skill groups may not be surprising. Flying-target shooting is unpredictable at the level of the momentary trajectory of a single target. However, it is highly predictable at the level of event type: the athlete does not need to devise or switch between multiple competing strategies, since he broadly knows what is going to happen in his surrounding environment, with targets launched at varying angles and speeds, and he can therefore plan to some extent in advance. In other words, the sport demands moment-to-moment attentional control rather than set-shifting between task rules, which is what cognitive flexibility tasks primarily index. The multifaceted nature of cognitive flexibility and its assessment may also explain the contradictory results (63). The issue becomes more complex given that different dimensions of cognitive flexibility follow different developmental trajectories (64). These findings may also be explained by differences between sports arising from training duration in secondary sports: stationary-target shooters may have had previous experience with flying-target skills, which prevents a clear-cut cognitive profile from emerging (58).

With respect to response inhibition, a significant difference between the two groups was observed in both response-accuracy components (congruent and incongruent). In contrast, the interference score, interference time, and the congruent and incongruent reaction times did not differ significantly. Our results are therefore partially consistent with those of studies (22, 29, 57-59, 66-67). A possible explanation for this

pattern is that flying-target shooters must suppress distracting stimuli in a variable environment and over a longer target trajectory, which places sustained demands on the accuracy of inhibitory control; this is not the case for stationary-target shooters, whose visual field and target position remain constant. The absence of group differences in the time-based indices suggests that the advantage lies in accuracy of inhibition rather than in the speed of interference resolution.

With respect to hot executive function, no significant difference between the two groups was observed. Our findings are consistent with those of study (58), the only study, to the best of our knowledge, that has examined hot executive function in a sports setting. Regarding hot executive function, researchers have noted that the available instruments lack adequate validity and reliability (68). During adolescence, the development of hot executive function proceeds slowly and follows a bell-shaped curve, leading to riskier decisions in mid-adolescence (33). This may influence the results and attenuate the environment's effect on executive function.

Our findings support the theory of far transfer. According to this theory, the smaller the difference in cognitive demands, the smaller the difference observed in executive function. Accordingly, in three of the four executive function domains we examined, no significant difference emerged, because the two sports impose broadly similar cognitive demands and train homogeneous cognitive skills; a significant difference appeared only in the component for which one group faced greater cognitive demands. This suggests that classifying sports as open or closed skills cannot serve as an adequate criterion for assessing the environment's effect on executive functions. An open-skill environment with moderate cognitive demands may exert the same effect as a closed-skill environment with comparable cognitive demands; the unpredictability of the environment alone cannot be regarded as an appropriate criterion for demonstrating its effect on executive function.

Limitations

It cannot be determined whether athletes with a particular pre-existing profile of cognitive abilities self-select into a given sport, or whether they acquire a specific set of cognitive skills within a sport environment (an experience-dependent account) (6). Improved psychometric properties are needed for several tasks that tap hot executive function (68). Potential confounding variables, such as intelligence, educational level, personality traits, academic performance, and socioeconomic status, which all influence executive function, were not controlled for (13).

Recommendations

Based on the findings of the present study, it is recommended that future specialized research not measure cold executive functions exclusively but instead assess hot executive functions using a domain-specific, cognitive approach. It is entirely conceivable that studies adopting a purely cognitive approach to skill components (excluding the affective component) may yield contradictory results. The effect of expertise becomes clearer as the focus shifts along the spectrum from sport-specific cold executive function to hot executive function. Research on larger samples and with longitudinal designs is required to achieve greater statistical power and more generalizable statements. Executive function is not a unidimensional construct; it varies across contexts and dynamically over the course of development. It is therefore recommended that, in order to delineate the domain of executive function and the role it plays in human development, particularly when addressing the influence of expertise on cognition, the dynamic relationship between brain function and brain structure be examined together with individual preferences, self-regulation, social context, individual information processing, temperament, and personal history.

Conclusion

The present study supports the theory of far transfer and indicates that classifying sports as open or closed skills is not a comprehensive taxonomy. Higher executive function cannot be expected based on environmental variability alone. Skilled and semi-skilled athletes in open-skill sports can anticipate environmental changes based on their experience, thereby introducing a degree of predictability comparable to that found in closed-skill sports. An athlete performing a closed skill may in fact need to plan a highly complex program before execution, even though the environment is familiar. A more precise classification of sports based on cognitive demands is therefore needed.

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Conflict of Interest

The authors did not have a conflict of interest.

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