

Correlation between Body Mass Index and Motor Competence in Students Aged 8–11: The Mediating Role of Hot and Cool Executive Functions

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Received: August 12, 2025; Revised: September 11, 2025; Accepted: October 11, 2025

Abstract

Background: Childhood obesity may negatively impact key developmental domains, including motor competence (MC) and executive functions (EFs). This study evaluated the relationship between body mass index (BMI) and MC, considering hot and cool EFs (hEFs and cEFs) as potential mediators in 8–11-year-old children.

Method: The was a cross-sectional study conducted in Hamedan, Iran, between 2023 and 2024. The study participants were 300 elementary school children (150 girls and 150 boys) randomly selected from two public schools. Motor competence (MC) was assessed using Bruininks–Oseretsky Test of Motor Proficiency (BOT); hEFs and cEFs were measured by applying the Balloon Analogue Risk Task and the Trail Making Test, respectively. Pearson correlation and hierarchical regression analyses were used for data analysis in SPSS version 26 ($P < 0.05$).

Results: BMI was negatively correlated with MC ($r = -0.308$) and hEFs ($r = -0.091$), but demonstrated no significant correlation with cEFs. MC was positively associated with hEFs ($r = 0.189$) but reversely correlated with cEFs ($r = -0.176$). Eventually, regression analysis indicated that BMI indirectly influenced MC through both hEFs ($P = 0.004$) and cEFs ($P = 0.011$).

Conclusions: Our findings revealed that the association between BMI and MC in children is mediated by hEFs and cEFs. Therefore, hEFs and cEFs should be taken into account when interpreting the relationship between BMI and MC, and improving motor competence may also benefit from children's executive functioning and overall health.

Keywords: Body Mass Index, Motor Activity, Cognition, Child

How to Cite: Layegh F, Arabi SM. Correlation between Body Mass Index and Motor Competence in Students Aged 8–11: The Mediating Role of Hot and Cool Executive Functions. Int J Sch Health. 2026;13(4):1-10. doi: 10.30476/intjsh.2026.108222.1550.

1. Introduction

Childhood obesity is increasingly recognized as one of the main public health crises of the 21st century (1). According to epidemiological studies in Iran, the prevalence of obesity and overweight among 6–16-year-old girls and boys is 4.5% and 8.8%, respectively (2, 3). The rising trend of obesity in early life not only undermines children's physical health but also impacts their psychological and cognitive development (4). Research indicated that body mass index (BMI) may be linked to various motor outcomes, including motor competence (MC) (5).

As one of the most important aspects of motor development in children, MC involves the ability to successfully perform fundamental motor skills, such as balance, coordination, throwing, and catching (6). A previous study reported a negative correlation between weight status or obesity and MC in children. Overweight children

are thought to face greater challenges in weight-bearing activities due to the greater gravitational load imposed by their additional body mass, which must be constantly overcome during weight-bearing movements (5). By contrast, a recent study of typically developing children aged 6–10 found a moderate and bidirectional relationship between cognitive function and MC (7). Although the link between BMI and MC is well-established, the mechanisms or variables that might mediate this correlation remain unclear. In addition, increasing evidence suggests a bidirectional correlation between executive function (EF) and obesity, indicating that obesity may be associated with impaired executive functioning (8).

EF comprises higher-order cognitive processes that enable individuals to regulate their behavior in complex and goal-directed contexts (9). Li and colleagues found that adolescents aged 8–16 years with higher BMI showed lower accuracy on working memory updating tasks compared to their

normal-weight peers (10). In contrast, Gunstad and co-workers observed no significant association between BMI and working memory updating in individuals aged 6–19. However, they found no notable differences in EF performance across weight categories, including underweight, normal weight, at-risk for overweight, and overweight (11).

Recent classifications have divided EFs into cool and hot types (cEFs and hEFs). cEFs involve cognitive skills (e.g., attention, cognitive control, and planning), while hEFs are more closely related to affective decision-making, emotional regulation, and self-control in emotionally charged or real-life situations (12). Principe and colleagues examined children aged 8–15 and concluded that adult-like performance on hEFs tasks emerges later in development than adult-like performance on cEFs tasks (13). Empirical evidence indicates that weight-related issues are linked to changes in both cEFs and hEFs (14). Moreover, EFs have been shown to directly influence eating behaviors (15). For instance, inhibitory control, a component of cEFs, may help suppress food-related thoughts or behaviors. Similarly, working memory, another cEFs component, can aid in maintaining and updating dietary goals to support healthy eating habits. Additionally, attentional shifting can redirect attention away from food cues toward more adaptive behavioral strategies. hEFs also play a critical role in eating regulation, because highly palatable foods act as strong rewards that activate the same brain reward pathways as addictive drugs. This overlap means that the same brain systems involved in substance craving and addiction can be triggered by food cues, making self-regulation especially challenging without intact hot executive functions (16). These hot executive processes are especially engaged in contexts involving emotional arousal, motivation, and conflicts between immediate gratification and long-term rewards (17). A meta-analysis examining the correlation between MC and EFs in children and adolescents aged 5–18 reported a small-to-moderate positive correlation between MC and EFs performance (18).

Considering the increasing incidence of childhood obesity and its documented effects on both physical and cognitive development, understanding the mechanisms that link body composition to MC is essential. EFs, particularly their hot and cool components, play a central role

in self-regulation, decision-making, and goal-directed motor behavior. Children with higher BMI often have weaknesses in these areas, which may make it harder for them to take part in physical activities effectively. hEFs, which involve emotion and reward processing, and cEFs, which involve cognitive control and attention, may affect motor performance in different ways. Despite their theoretical relevance, no previous studies, based on the literature search, have examined the potential role of hEFs and cEFs in explaining the association between BMI and MC. Also, The inconsistent findings, along with the limited body of research, underscore the need for further investigation into the association between BMI and certain components of executive functioning (10, 11). Therefore, the present study aimed to examine the association between BMI and MC in 8–11-year-old children, and to clarify the extent to which hEFs and cEFs may mediate this relationship.

2. Method

2.1. Design

This was a cross-sectional study conducted in in Hamedan, Iran, between 2023 and 2024.

2.2. Selection and Description of Participants

The participants were 300 elementary school students aged 8 and 11 years old (150 boys and 150 girls), who were randomly selected from schools in Hamadan, Iran. Two public elementary schools (one for boys and one for girls) were randomly chosen from a list provided by the Department of Education. The participants were categorized according to the World Health Organization's BMI-for-age percentiles; they had a normal weight if they were between the 5th and 84th percentile (19). Those between the 85th and 94th percentile and above the 95th percentile were overweight and obese, respectively. The inclusion criteria were: (1) normal cognitive abilities as evidenced by school performance, (2) age range of 7–11 years old, (3) no physical or neurological disorders, and (4) premenarchal status for girls. On the other hand, children were excluded if they were classified as severely underweight (BMI below the 5th percentile) or if they had congenital structural abnormalities, cerebral palsy, or any diagnosed motor disorders (20).

2.3. Sample Size Determination

The sample size was estimated a priori by employing G*Power version 3.1. Considering that this study primarily sought to investigate the correlation between BMI and MC, the initial calculation was based on a Bivariate Normal Model Correlation (two-tailed). The parameters entered into G*Power were a desired statistical power ($1-\beta$) of 0.85, an α error probability of 0.05, and an expected correlation (ρ_{H_1}) of 0.17, derived from small-to-medium effect sizes reported in previous study (21). This calculation estimated a minimum required sample size of 270 participants. To ensure adequate statistical power, a slightly larger and more conservative sample size was selected for the subsequent hierarchical multiple regression analysis (fixed model, R^2 deviation from zero), which examined the mediating role of hot and cool executive functions using three predictors: motor competence, hEFs, and cEFs. A separate power analysis for the multiple regression model, assuming an α of 0.05, a power of 0.85, 3 predictors, and a conservative small-to-medium effect size ($f^2=0.05$), indicated a required minimum of approximately 290 participants. Accordingly, 300 elementary school students were recruited (21), who fully met the requirement for the primary correlational objective and ensured sufficient statistical power for all planned analyses, including the mediation model.

2.4. Data Collection and Measurements

2.4.1. Bruininks–Oseretsky Test of Motor Proficiency (BOT): Motor competence (MC) was evaluated by the Bruininks–Oseretsky Test of Motor Proficiency (BOT). The original test was developed by Bruininks and colleagues, with the final revised edition published in 1978. The full version consists of eight subtests comprising 46 items, providing a comprehensive assessment of fine motor and gross motor skills (22). The short version includes the same eight subtests but uses only 14 selected items, allowing for quicker administration. Gross motor skills are measured through four subtests: balance, running speed and agility, strength, and bilateral coordination. Moreover, fine motor skills are assessed via three subtests: visual–motor control, response speed, and upper-limb speed and dexterity, along with an additional subtest, upper-limb coordination, which assesses coordination of the arms and shoulders. Scores from these subtests

are combined into a Total Motor Composite score, representing the child's overall motor competence. Test–retest reliability was 0.78 for the full form and 0.86 for the short form. The construct validity of BOT was supported by coefficients around 0.84 in previous research (23). Its content validity was confirmed using a content validity ratio of 0.72 and a content validity index of 86%, indicating the instrument's adequacy (24).

2.4.2. Balloon Analogue Risk Task (BART): Hot executive functions (hEFs) was evaluated using the Balloon Analogue Risk Task (BART). This computer-assisted task was first designed by Lejuez and colleagues to measure real-world risk-taking behavior (25). In this task, participants see a balloon on the computer screen and can inflate it incrementally by pressing a key. With each pump, a small amount of virtual money is added to a temporary bank. Participants may choose to stop inflating at any time by clicking the 'Collect Money' button, transferring the accumulated amount from the temporary bank to a permanent bank before moving on to the next balloon. However, the entire amount in the temporary bank is lost if the balloon bursts before the participant collects the money. The task includes 30 balloons, and the explosion point of each balloon is unpredictable, introducing an element of uncertainty. This design simulates real-life risky decision-making under ambiguity and reward conditions (25). Higher average pumps before collecting money indicate a greater tendency toward risk-taking. Content validity was also supported, with a content validity ratio of 0.80 and a scale-level content validity index (S-CVI) of 0.87, reflecting satisfactory agreement among experts regarding clarity and relevance of the items (26).

2.4.3. Trail Making Test (TMT): Cool executive functions (cEFs) was evaluated using the Trail Making Test (TMT), a paper-based neuropsychological assessment originally developed by the U.S. Army in 1944 as part of the Army Individual Test Battery (27). TMT is widely employed to assess psychomotor speed, visual attention, cognitive flexibility, task switching, sequencing, and the ability to plan and adjust ongoing tasks, making it a reliable indicator of overall cognitive functioning (28). The test comprises two parts; part A involves connecting 25 numbered circles (1–25) randomly arranged on a sheet of paper in ascending numerical order (e.g., 1 → 2 → 3). This section primarily evaluates visual

search ability and working memory for sequencing; part B includes 24 circles, half numbered (1–12) and half containing letters (A–L). Participants must alternate between letters and numbers sequentially (e.g., $1 \rightarrow A \rightarrow 2 \rightarrow B \rightarrow 3 \rightarrow C$), engaging set-shifting, working memory, and divided attention. TMT Part B is considered highly sensitive to executive function (EF) and is extensively regarded as a strong measure of overall executive performance (29). This test has also been validated for use in Iran (30).

2.5. Procedure

Permission for conducting the study was obtained from the Education Department of Hamadan Province, Iran. Arrangements were then made with school principals to facilitate data collection in classrooms. Class lists were obtained from each school. Students aged 8–11 years were identified, and eligible participants were selected using a simple random sampling technique. Each participant's height and weight were measured with a standard scale and measuring tape, and BMI was calculated accordingly. With the assistance of school administrators and teachers, students with disorders (e.g., attention-deficit/hyperactivity disorder, learning disabilities, intellectual delays, and conduct disorders) were identified and excluded, as were students who had reached puberty. The Balloon Analogue Risk Task (BART) was explained individually to the selected students, who completed the test one by one in a quiet room using a laptop in a stress-free environment. Simultaneously, other students completed the TMT using paper and pencil in the classroom. Instructions were provided clearly, and participants used colored pencils to perform the tasks. Moreover, completion times for each section were recorded in seconds using a smartphone stopwatch. After a brief break, fine motor skill tasks from BOT were administered in the school health room, while gross motor skill tasks were conducted outdoors on the playground. The parents of all participants signed a written informed consent before the start of the study.

2.6. Data Analysis

The obtained data were analyzed by SPSS version 26. Descriptive statistics (means and standard deviations) and Pearson correlation coefficients were employed to investigate the

correlation among the variables. In addition, hierarchical regression analyses were conducted to evaluate the mediating role of hEFs and cEFs in the correlation between MC and BMI. In the first block, BMI was entered as the primary predictor. MC scores (BOT) were added in the second block, followed by hEFs and cEFs scores in the third block as potential mediators. This approach allowed for the assessment of the incremental contribution of each set of variables to the explained variance. A significance level of $P < 0.05$ was considered for all of the statistical tests.

3. Results

The participants were 300 elementary school students aged 8 and 11 years old (150 boys and 150 girls), who were randomly selected from schools in Hamadan, Iran. All participants met the inclusion criteria of having normal cognitive ability, suffering from no physical or neurological disorders, and, for girls, being prepubertal. Children who were severely underweight (BMI below the 5th percentile) or had congenital abnormalities or diagnosed motor or neurological impairments were excluded from the investigation. Table 1 summarizes the participants' demographic and descriptive characteristics, including age, BMI, MC, and hEFs and cEFs scores by gender.

Pearson correlation analysis was performed to examine the correlation among the study variables (Table 2). Based on the results, the Pearson correlation coefficient between BMI and gross motor skills, fine motor skills, and coordination was -0.417 , -0.055 , and -0.089 , respectively. The correlation between BMI and hEFs was -0.091 , while the correlation between BMI and cEFs was 0.037 . Additionally, hEFs was positively associated with MC ($r = 0.189$), whereas cEFs showed a negative association ($r = -0.176$). The analysis of variance and regression analyses further indicated a significant relationship between BMI and MC, mediated by the combined effects of hEFs and cEFs ($P < 0.001$). Table 3 presents the effects of BMI, hEFs, and cEFs on children's motor competence.

Although no formal mediation analysis was performed, hierarchical regression results revealed that both hEFs and cEFs could significantly enhance the prediction of MC ($P = 0.004$ and $P = 0.011$), suggesting their potential mediating role in the correlation between MC and BMI.

Table 1: Descriptive statistics and group comparisons of study variables

Gender	Quantity	Variable	Average	Standard Deviation	Minimum	Maximum
Girl	150	Age	9.67	1.20	8	11
		BMI	19.23	3.3	13.4	28.3
		Motor Competence	51.53	8.49	32	72
		Gross Motor Skills	24.81	5.38	13	38
		Fine Motor Skills	23.33	3.99	13	35
		Coordination	3.41	0.88	1	6
		Hot Executive Function	5807.91	1884.2	1450	9690
		Cool Executive Function	154.14	62.27	-42	259
Boy	150	Age	9.47	1.69	8	11
		BMI	19.18	3.82	13.8	42.2
		Motor Competence	52.18	7.18	34	72
		Gross Motor Skills	24.47	4.67	14	38
		Fine Motor Skills	23.95	4.31	13	36
		Coordination	3.83	0.86	1	6
		Hot Executive Function	5868.01	1990.2	2000	10250
		Cool Executive Function	146.28	68.26	17	264

BMI: Body Mass Index

Table 2: Correlations between body mass index, motor competence, and executive functions

	BMI	P value	Motor Competence	P value
Gross Motor Skills	-0.417	<0.001*		
Fine Motor Skills	-0.055	0.337		
Coordination	-0.089	0.118		
Hot Executive Function	-0.091	0.11	0.189	0.001*
Cool Executive Function	0.037	0.513	-0.176	0.002*

P<0.05; BMI: Body Mass Index

Table 3: Regression coefficients for body mass index and executive functions predicting motor competence

Variable Index	Regression Coefficient	Standard Deviation	Standard Regression Coefficient	t-statistic	P value
Motor Competence	-0.699	0.143	-0.316	-4.888	<0.001
BMI/ Hot Executive Function	0.00319	0.0001	0.173	2.908	0.004
BMI/ Cool Executive Function	-0.001	0.0001	-0.153	-2.572	0.011

BMI: Body Mass Index

4. Discussion

This study investigated the correlation between MC and BMI in students aged 8–11 years old, with special attention to the potential mediating role of hEFs and cEFs. The results confirmed that higher BMI was associated with lower MC, while no significant direct correlation was observed between BMI and either type of EF. Notably, MC was significantly associated with both hEFs and cEFs. Furthermore, hierarchical regression analyses indicated that both types of EFs considerably contributed to predicting MC when added to the model. Although no formal mediation analysis was conducted, these findings support the potential mediating role of hEFs and cEFs in the association

between MC and BMI.

Our results demonstrated an inverse correlation between MC and BMI in school-aged children. This finding is consistent with those of Barnett and co-workers indicating that excess weight in children is associated with reduced participation in physical activities, impaired balance, and lower proficiency in fundamental motor skills (31). As BMI increases, agility and coordination tend to decline, limiting children's opportunities for motor experiences. Additionally, metabolism and energy expenditure are noticeably altered in children with higher BMI. The greater physiological demands of motor activities often lead to earlier fatigue and reduced exercise tolerance. This metabolic inefficiency is

particularly evident during prolonged physical activities, where children with higher BMI expend more energy than their peers with lower body mass (32).

On the other hand, the findings of this study revealed no considerable association between hEFs and BMI. This finding aligns with the previous research (33), suggesting that in children with an increased BMI—but without severe obesity—dopaminergic system-related neural alterations may not yet have developed sufficiently to significantly affect hEFs (34).

No significant association was found between BMI and cEFs, consistent with the result of previous research (15). However, this finding contradicts the results reported by Favieri and co-workers, identifying a moderate negative correlation between BMI and cEFs (35).

Another key finding was the positive association between MC and hEFs, which corroborates the results of previous research (33). This association in children aged 8–11 years old may be explained by their shared reliance on overlapping brain regions, including the prefrontal cortex and cerebellum. These areas are critical for decision-making, emotion regulation, planning, and motor coordination. Engagement in physical activities (e.g., exercise and dance) can strengthen these brain regions, thereby enhancing both motor skills and executive functioning (36).

Additionally, the negative association between cEFs and MC is in line with previous findings (37). Contrary to initial expectations, this pattern may be explained from a cognitive-behavioral perspective. Children who are more actively engaged in motor activities may show lower levels of concentration in structured cognitive tasks, such as those assessing cEFs (38).

The observed associations may be explained by the interplay between physiological constraints and cognitive regulation. Excess body weight can impair motor proficiency by limiting biomechanical efficiency, reducing endurance, and altering movement patterns (39). Simultaneously, children with higher BMI often exhibit deficits in EFs due to neurodevelopmental changes, particularly in prefrontal regions responsible for self-regulation and motor planning (9). These

cognitive impairments may hinder their ability to initiate, sustain, and adapt motor behaviors, thereby mediating the impact of BMI on MC. Importantly, our results indicated that both hEFs and cEFs can mediate the relationship between BMI and MC. This mediating role aligns with theoretical frameworks emphasizing cognitive-motor interactions in child development (40) and extends them by differentiating between hot and cool components. Our findings highlighted how EFs shape behaviors critical for physical activity and skill acquisition, which is consistent with the results of previous research (23), which revealed associations between EF and motor skills, regardless of the mediating role of BMI. Children with higher BMI are often less physically active and engage in more sedentary behavior, which can adversely affect motor skill development (14). EFs, however, play a key role in regulating these behaviors. For instance, cEFs (e.g., working memory and inhibitory control) allow children to maintain focus, resist distractions, and effectively plan movements—all essential for acquiring and refining motor skills. Impairments in these functions, commonly observed in children with higher BMI, may limit their engagement in and benefit from physical activities that promote MC (41). Similarly, hEFs support motivation and decision-making in emotionally or socially charged contexts. A child's ability to regulate emotions, control impulses, and sustain motivation during challenging tasks (e.g., learning new motor skills or participating in competitive games) is critical. Children with higher BMI may face social stigma or reduced self-esteem, which can diminish their motivation to engage in group activities or sports. Strong hEFs can help overcome these emotional barriers, enabling children to persist and participate in activities that enhance motor skills (6). Overall, the mediating role of EFs reflects their influence on behavioral patterns associated with BMI and their contribution to MC development.

In addition, the present study offers several methodological and conceptual strengths. The relatively large and gender-balanced sample ($N=300$; 150 girls and 150 boys) enhanced statistical power and supported the robustness of the findings. In addition, the simultaneous assessment of hEFs and cEFs provided a differentiated view of cognitive regulation. Furthermore, the use of validated instruments (BOT, BART, and TMT) ensured measurement precision and reliability.

By integrating motor, cognitive, and physiological variables, the study contributed a multidimensional perspective to the understanding of child development.

4.1. Limitations

This study had some limitations. The cross-sectional design prevented causal inference, and the geographically localized sample may have limited the generalizability of the results to broader populations. Additionally, EFs were assessed exclusively through behavioral tasks, without neurophysiological or imaging-based measures that could provide deeper insights into underlying mechanisms. Moreover, psychosocial factors (e.g., motivation, emotional state, and social context) were not examined, despite their potential influence on both MC and executive functioning.

5. Conclusions

The findings of the present study demonstrated significant associations between BMI, MC, and both hEFs and cEFs in children. Specifically, higher BMI was associated with lower MC, while no direct correlation was observed between BMI and either type of EF. Notably, MC, a crucial developmental factor, was positively related to hEFs and negatively associated with cEFs. Hierarchical regression analyses further indicated that hEFs and cEFs may mediate the relationship between BMI and MC, underscoring the cognitive pathways through which body composition influences motor development. These findings carry important implications for educational and health interventions. Schools and educators should integrate structured physical activities and cognitively engaging games into daily routines, particularly for children with higher BMI. In addition, tailored movement-based programs have the potential to enhance not only MC but also executive functioning, thereby supporting academic achievement, emotional regulation, and social development during the early school years. Future longitudinal and multimodal research is needed to clarify these developmental pathways. Practically, school-based interventions combining cognitively engaging and emotionally supportive physical activities may enhance both EFs and MC, especially in children with higher BMI, thereby informing future educational and preventive health policies.

Acknowledgment

This article was extracted from the MSc thesis of Ms. Fatemeh Layegh at the Department of Motor Behavior, Bu-Ali Sina University, Hamedan, Iran. Also, the authors would like to acknowledge the participants who took part in the study.

Declaration of AI

The authors acknowledge the use of AI-assisted tools (ChatGPT) for language editing. All content was manually reviewed and edited by the authors to ensure its accuracy and academic integrity; the authors take full responsibility for the final content of the manuscript.

Authors' Contribution

Fatemeh Layegh: Contribution to the collection and interpretations of data; reviewing the work critically for important intellectual content. Seyedeh Manizheh Arabi: Contribution to the conception and design of the study; analysis and interpretations of data; drafting the work. All authors have read and approved the final manuscript and agree to be accountable for all aspects of the work, such that the questions related to the accuracy or integrity of any part of the work.

Conflict of interests: None declared.

Funding: None.

Ethical Approval

The Ethics Review Board of Bu-Ali Sina university approved the present research with the code of IR.BASU.REC.1402.081. Also, written informed consent was obtained from the participants.

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