Canli *et al. BMC Pediatrics* (2025) 25:153
https://doi.org/10.1186/s12887-025-05475-1

BMC Pediatrics

RESEARCH Open Access

Unveiling the predictive role of motor competence and physical fitness on inhibitory control in preschool children: a cross-sectional study

Umut Canli[1], Aytaç Güt[2], Sevi Baloğlu Sevinç[2], Meral Deveci[3], Ali Mert Şendil[1], Gülyüz Yaman[4] and Monira I. Aldhahi[5*]

Abstract

Background During the preschool years, children experience rapid development of inhibitory control (IC). This period is also crucial to foster the establishment of the foundations of physical fitness (PF) and motor competence (MC), which are essential for long-term health outcomes. This study aimed to investigate the predictive roles of PF and MC in IC in preschool children.

Method A total of 139 children (78 boys and 61 girls) participated in the study, with a mean age of 5.76 ± 0.30 years and a body mass index (BMI) of 16.15 ± 1.94 kg/m^2. Children performed the Go/No-Go test, Körperkoordinationstest für Kinder (KTK3+) test, static and dynamic balance tests, a pro-agility and countermovement jumping (CMJ) test.

Results The findings showed that there was a positive association between MCT and accuracy number (AC) (go) (β = 0.079, 95%CI: 0.051–0.107), AC (no go) (β = 0.022, 95%CI: 0.003–0.041). However, between MCT and reaction time (RT), there was a negative relationship (β = −0.497, 95%CI: −0.988 - −0.006). MCT scores showed a significant positive relationship with AC (go), with a beta coefficient of 0.309 (95% CI: 0.181, 0.436). This finding further underscores the robustness of this relationship. The PF indicator agility showed a negative relationship with AC (go) (β = -3.638 [-5.590, -1.687]) and static balance was negatively related to RT (β = -34.767, 95% CI [0.018, 0.165]).

Conclusions Overall, this study indicates that MC, rather than general PF, is strongly associated with the concurrent level of IC during the preschool period. These findings highlight the potential importance of promoting MC through targeted interventions that may support cognitive function in young children. Further longitudinal research is recommended to explore the causal relationships and long-term effects of these interventions.

Study registration Research protocol number: 2022.214.11.15.

Keywords Agility, Balance, Preschooler, Executive functions, Strength

*Correspondence:
Monira I. Aldhahi
mialdhahi@pnu.edu.sa
[1]Faculty of Sports Sciences, Tekirdağ Namık Kemal University, Tekirdağ, Turkey
[2]Faculty of Economics and Administrative Sciences, Tekirdağ Namık Kemal University, Tekirdağ, Turkey
[3]Vocational School of Health Services, Tekirdağ Namık Kemal University, Tekirdağ, Turkey
[4]Tekirdağ National Education Directorate, Tekirdağ, Turkey
[5]Department of Rehabilitation Sciences, College of Health and Rehabilitation Sciences, Princess Nourah bint Abdulrahman University, P.O. Box 84428, Riyadh 11671, Saudi Arabia

Background

Cognition refers to the mental processes involved in acquiring knowledge and understanding through thought, experience, and sense. Within the domain of cognition, executive functions (EF) are a subset of cognitive processes that enable individuals to manage their thoughts, actions, and emotions in order to achieve goals [1]. The EF appear to function as a specific component of cognitive functioning necessary for various life outcomes in children [2–4]. Therefore, there is significant interest in improving EF in children, contributing to their development, and addressing deficiencies in this regard [5].

While EF are important for children's cognitive and emotional growth, inhibitory control (IC), is particularly pertinent during the preschool years, as it lays the groundwork for future executive functioning and cognitive development [2, 6]. IC is crucial for self-regulation and fundamental to more complex cognitive processes. This allows individuals to override instinctive responses in favor of more appropriate actions that align with their goals. Recently, some studies have associated EF with motor competence (MC). It is of major importance in children and is defined as proficiency in the coordination of basic motor skills, especially movements such as locomotor and object control. At this point, MC can significantly affect both daily life and developmental trajectories [7]. The relationship between MC and EFs in children is thought to be fundamentally intertwined due to the involvement of the same brain areas in both EF and MC development [7]. Motor competence, which involves coordination and control of physical movements, is essential for children's interactions with their environment. Studies have shown that better motor skills are associated with more efficient cognitive function, including IC and working memory [8]. Deficiencies in EF and MC are commonly reported in children with developmental disorders [9]. Applied research has demonstrated indirect relationships between MC and EF in developmental disorders such as attention-deficit/hyperactivity disorder [10] and developmental coordination disorders [11].

Another issue observed in children is their low level of physical fitness (PF) [12]. PF represents the ability to engage in daily activities and is a significant indicator of physical and mental health [13]. Although guidelines recommend that preschool children engage in one to two hours of moderate to vigorous daily physical activity [14], the findings indicate that many children in this group exhibit a lower activity level [15, 16]. This situation contributes to lower PF levels in preschool children. Children with higher levels of PF exhibit better attention system efficiency, prefrontal cortex activation, and EF [17, 18]. Previous studies have demonstrated an association between PF and IC, with greater emphasis on children and adolescents in most studies [18, 19]. IC is a fundamental parameter of EFs that represents an individual's ability to inhibit dominant behaviors unrelated to current tasks [20]. Individuals with good IC can overcome strong instinctive tendencies and resist external temptations by controlling their attention, behavior, thoughts, and/or emotions [21]. IC typically emerges in the preschool period and forms the foundation for the development of advanced cognitive processes in adulthood [22].

Preschool is considered the optimal period for the development of IC [23].Well-developed IC during this period is associated with future intellectual development, academic performance, and health status [24, 25]. Therefore, promoting IC development in preschool children is crucial from a public health perspective. However, the relationship between PF and inhibitors has rarely been explored in preschool children, despite the rapid development of IC during this stage [26]. Furthermore, there has been a significant interest in the relationship between MC and cognition in preschool children. However, there is insufficient evidence to establish a relationship between MC and IC in preschool children. Additionally, it is emphasized that further studies are needed. Preschool children are at a crucial stage in the development of both MC and IC [27, 28].

Moreover, the relationship between IC and MC and PF is crucial to understanding because both MC and PF have been linked to improved cognitive outcomes in children [29, 30]. MC involves coordination and control of physical movements, which are essential for children's interactions with their environment. On the other hand, PF is indicative of overall physical health and has been associated with cognitive and academic benefits. This understanding provides a rationale for initiating intervention studies designed to improve MC and PF in preschool children [31]. By focusing on IC as a key component of EF and its association with MC and PF, this study aimed to shed light on how these components interact to influence the development of young children. Upon reviewing the literature, it is evident that the existing research predominantly explores the relationships between EF, MC, and PF [7, 26, 31–33]. However, no studies have concurrently examined the interconnections between EF, MC, and PF in children. Therefore, this study aimed to investigate the relationships between MC, PF, and IC components as specific aspects of EFs in preschool children. Based on this framework, we hypothesized that both MC and PF will demonstrate positive associations with IC in children aged 4–6 years.

Methods

Design of the study and participants

This is a cross-sectional study that has been approved by the Ethics Committee of Tekirdag Namik Kemal

University Faculty of Medicine (Research protocol number: 2022.214.11.15). Subsequently, a formal invitation to participate in the study was extended to preschools. Four public kindergartens in the city where the study was conducted were approached to participate. Of these, only one public kindergarten approved this study. The participants aged 4–6 years had a mean age of 6 ± 1 years. The participant recruitment process is presented in a flowchart (Fig. 1). In the initial stage, research permission was obtained from the school administration, and official permission was obtained from the National Education Directorate to which the school was affiliated (Reference Number: E-43996270-44-63592582 Date: 15/11/2022). The school administration provided information about the research protocol and process to teachers and student groups. Voluntary and parental consent forms were distributed to all students. Informed consent was obtained from the parents or legal guardians.

Based on previous studies [7, 8, 11], we performed a priori sample size calculations using Statistical Power and Sample Size Calculations in R package [34]. Using the lowest reported correlation coefficient ($r = 0.24$) [7, 8, 11], an alpha level of 0.05, and a power of 0.80, a minimum sample of 133 participants was required. Participants were selected using a convenient cluster sampling method. Only those whose parents or guardians provided written informed consent were included in the study. The exclusion criteria ensured the selection of typically developing children and excluded those with documented medical conditions affecting physical, cognitive, or motor development, such as neurological or musculoskeletal disorders. Additionally, children who were unable to complete the required assessments due to illness or other health issues, those absent during critical stages of data collection, or those who withdrew from the study were excluded. A total of 152 children from this kindergarten were invited to participate in this study. Among them, 139 (78 boys and 61 girls) met the eligibility criteria and were included in the final sample.

Study procedure

This cross-sectional study involved conducting multiple assessments over two consecutive days to reduce participant fatigue and enhance the quality of the data collected. The study followed a fixed test order with defined time intervals to ensure consistency and reliability in data collection. The researchers provided both theoretical and practical explanations of the test and measurement protocols to the participants before the assessments. On the first day, testing was started between 09:30 and 11:00. Firstly, participants completed a form capturing their descriptive characteristics, followed by the administration of the Go/No-Go test to assess executive function. Anthropometric measurements including height and body weight were recorded. The first day also included motor coordination tests, specifically KTK3 + tasks.

On the second day, all tests were conducted between 09:30 and 11:00 to minimize the effects of circadian rhythms on performance outcomes. Assessments of PF were conducted, included balance performance measurements, the agility test (Pro-Agility Test), and the Countermovement Jump (CMJ) test. The tests were

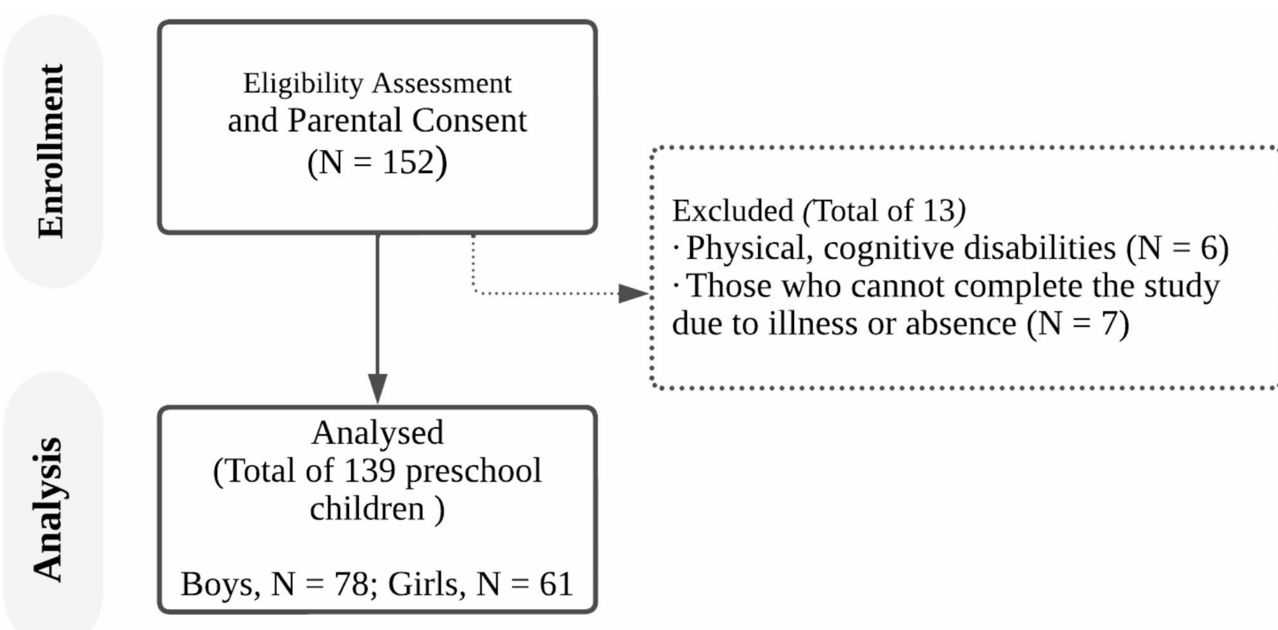

Fig. 1 Flowchart of participant recruitment

administered in the same order to all participants to ensure consistency. Prior to the PF assessments, participants underwent a standardized warm-up consisting of 5 min of jogging and 5 min of dynamic stretching. Cool-down exercises were performed after the completion of the tests.

Assessments

Body composition Assessment

The height (cm) was measured using a Mesilife 13,539 portable stadiometer with an accuracy of 0.1 cm. A stable eight-polar tactile electrode bioelectrical impedance analyzer (Tarti Fast, Japan) was used to measure body mass (kg). The validity of this bioelectrical impedance analyzer has been previously reported [35]. Body mass index (BMI) (kg/m^2) was calculated by dividing body mass (kg) by body height squared (m^2).

Inhibitory control (IC) assessment

The Go/No-Go Test was used to assess IC using measures derived from the psychometrically validated Early Years Toolkit for preschool children [36].The convergent validity of the IC measurement showed a strong relationship with the commonly used and structurally similar NIH Toolbox for this age group [37, 38] ($r\ (80) = 0.40$, $p < 0.001$). Additionally, internal consistency analyses of the Go/No-Go task revealed good reliability for the "Go" stimulus (Cronbach $\alpha = 0.95$) and the "No-Go" stimulus (Cronbach's $\alpha = 0.84$) [36].

The Go/No-Go test assesses the ability to inhibit and control behavioral impulses [39]. This test was administered on an iPad, and the children were expected to respond appropriately to the displayed fish and sharks on the screen. Following predetermined protocols [40, 41], during the "Go" trials, a fish is displayed on the screen, and children are expected to respond by touching the screen ("catching the fish"). However, during the "No-Go" trials, a shark is displayed, and children are instructed not to touch the screen ("don't catch the sharks"). The majority of stimuli used in the test (80%) are "go" trials (fish), creating a pre-existing tendency to provide a strong response. Therefore, participants need to inhibit this strong response during "no-go" trials (20% sharks). Reaction time (RT) was measured as the time taken to respond to the "Go" stimuli and recorded in milliseconds (ms) with an accuracy level of ± 1 ms, ensuring precise and reliable measurements. This measure is commonly used to assess processing speed, attention, and efficiency of cognitive control. In a Go/No-Go test, the accuracy number (AC) can be expressed in both formats, either as a percentage (%) and typically calculated as Accuracy = (Correct Responses divided by Total Responses × 100) or as the absolute number of correct responses (n). In our study, we opted to report the absolute counts (n) as a continuous variable. This decision was based on the specific analytical framework of the study, in which the raw count of correct responses provided greater granularity for statistical modeling and interpretation.

Upon the initiation of the test trials, the initial rounds were used to familiarize the participants with the task and provide practice opportunities. Participants completed 20 practice trials, followed by 75 test trials, divided into three blocks of 25 stimuli each. RT and AC were recorded as the key measures. The total test duration was approximately 5 min per participant, including instructions and breaks [42]. Each stimulus was displayed on the screen for 1.50 s, followed by a 1.00-second break before moving on to the next stimulus.

Motor competence (MC)

Motor competence performance and levels were determined using the Körperkoordinationstest für Kinder (KTK) test battery. The KTK test was initially developed by Kiphard and Schilling in 1974 and modernized in 2007 [43, 44]. To evaluate children's and adolescents' MC, the KTK3 [43, 44], including tasks to evaluate Eye-Hand Coordination (EHC) [45]. KTK3 has been used to evaluate general gross motor coordination [46].The global use of these well-proven, dependable, and product-oriented (quantitative) test instruments is common [44].

The KTK3 consists of three components that assess MC. Jumping Sideways (JS) in which the participants are required to jump laterally over a wooden slat using both feet for a duration of 15 s. The final score was determined by the total number of jumps completed in the two trials. In the Moving Sideways (MS) test, the participants moved laterally along a straight line using two wooden platforms for 20 s. The score was based on the sum of the number of successful platform placements and the number of steps taken on the platforms during the two trials. In Backward Balancing (BB), participants performed balance tests on beams of decreasing widths (6, 4.5, and 3 cm), with three attempts per beam. A maximum of eight steps per trial on each beam are recorded, leading to a total possible score of 72 steps. The test battery was revised by Platvoet et al. [45] and was named KTK3+. The KTK3 + test included BB, MS, JS, and EHC tasks. This assessment involves rapidly alternating between throwing and catching a tennis ball with both hands (e.g., tossing with the left hand and receiving with the right, and then vice versa) for a duration of 30 s. The participants stood 1 m away from the wall during the test. They were instructed to aim the ball at eye level toward a 1 m^2 square taped on the wall, with the square's bottom edge positioned 1 m above ground level [47]. Performance was scored based on the number of successful catches out two attempts at 30 s [45, 48]. The KTK3 + test scoring system involves summing the raw scores for each test item and converting them into a Motor Quotient (MQ) based on age, sex, and test item using separate means and standard deviations for boys and girls. As reported by Canli et al. [49], the Turkish version of the KTK3 + showed high content and construct validity, with appropriate confirmatory factorial validity indices ($\chi^2 = 0{,}370$, χ^2 /df = 0,995, GFI = 0,999, AGFI = 0,994, CFI = 1,000, RMSEA = 0,000). Factor analysis with multidimensional scaling demonstrated that the one-dimensional model provided the best fit, with all test items correlating to the same latent construct: "MC" This was further supported by moderate-to-good correlations between all four test items ($r = 0.453–0.799$) [48].

Physical fitness (PF)

Balance performance

Balance levels were assessed using the SensBalance Miniboard (Sensamove, Utrecht, Netherlands), a dynamic platform equipped with high-precision sensors that measure postural sway and weight distribution. The measurement device used was based on an innovative and non-intrusive technology that records data in real time and can save them in data files, Excel files, and graphical formats. The described measurement device allows testing not only static and dynamic balance but also proprioceptive balance related to ankle range of motion [50]. Static balance measures the ability to maintain a stable position while standing still. It detects subtle shifts in the weight distribution and provides feedback on the ability to control these movements. Children were asked to stand as still as possible on the Miniboard for a set duration, typically approximately 30 s. They were instructed to maintain their posture without significantly shifting their weight. Dynamic balance (bipodal and unipodal) was assessed as the ability to maintain balance while performing movements or responding to changing conditions. This includes horizontal (left-right) and vertical (forward and backward) shifting weights, simulating real-life situations in which balance is required. The percentages indicate performance levels and the average measurements of four-directional (side-to-side) oscillations in degrees [50]. The results included average oscillations in degrees for each direction (horizontal and vertical), and performance levels expressed as percentages (%). The performance level (%) was calculated as (1 – Maximum Allowable Oscillation divided by the Measured Oscillation Amplitude ×100).

Agility test (pro-agility test)

The Pro-Agility Test (also known as the 20-Yard Shuttle) is designed to measure quick directional changes and acceleration. Three markers (cones) were used in this study. The central marker was positioned at the starting line. Two additional markers were placed at a distance of five yards (4.57 m) on either side of the central marker. Telemetric chronometer sticks (Sinar Fotocell, Karabuk, Turkey) were set up at the central starting line to accurately measure the time elapsed during the test. At the start, they touched the marker on the right side first, followed immediately by touching the marker on the left side. The test was concluded when the participant passed the starting line. The time for the entire sequence (right marker → left marker → back to the start) was measured using the telemetric chronometer system, ensuring precise measurement of the elapsed time. All measurements were performed twice. A rest interval of 2–3 min was provided between measurements, and the shortest time (in seconds) of both measurements, with seconds representing the unit and its accuracy [51].

Countermovement jump (CMJ)

Jump performance was measured using an accelerometer system (IVMES; Ankara, Turkey). The device was attached to a belt and was fixed vertically to the middle of the waist. The participants were instructed to avoid involuntary movements that could affect the jumping height in the vertical plane during the jump. During the test, participants were encouraged to jump as high as possible. The test protocol allowed the arm swing to mimic natural jumping conditions. In addition, the participants were instructed to ensure that their legs remained extended during the flight phase to optimize the consistency of the measurements. The system records acceleration in the vertical plane throughout the jump, starting from the initial countermovement phase (bending the knees) to the take-off and flight phase, and finally landing. The test was conducted twice with rest intervals between attempts set at 30–60 s. Raw acceleration data captured by the device were processed to calculate the jump height. This transformation is typically performed using kinematic equations, in which the maximum vertical velocity achieved during the jump is used to estimate the height reached. Jump heights were measured in centimeters (cm) with an accuracy of ± 0.1 cm, ensuring precise measurement for statistical analysis. The highest jump performance in both trials was used for statistical analysis [52].

Statistical analysis

We analyzed the data using the R language-based Empower Stats software for statistical analysis. Prior to the primary analysis, screening for normality and outliers was performed using the Shapiro-Wilk test. Descriptive statistics, including mean and standard deviation, were computed for all outcome variables.

The scores for each index were transformed into standard scores, with a mean of 50 and standard deviation (SD) of 10. As the agility test had a negative correlation with speed, the score was multiplied by -1 and then standardized. The standard score formula for PF and MC was as follows: T = [(X – M) / SD] × 10 + 50 (where X is individual performance and M is the mean). The sum of each standard score was recorded as the Physical Fitness T-score (PFT), defined as ($T_{agility}$ + $T_{static\ balance}$ + $T_{dynamic\ balance}$ + T_{CMJ}). The Motor Competence T-score (MCT) was recorded as: (T-BB + T-JS + T-MS + T-EHC).

The relationship between PFT, MCT and their components, and IC (AC and RT) was tested. Model 1 is tested without any adjustments and Model 2 is adjusted for age, sex, and BMI. A linear regression model was used to test the relationship between the independent variables (PF components (agility, static balance, dynamic balance, and CMJ), MC (BB, JS, MS, EHC), PFT, and MCT) and dependent variables (IC components (AC go, AC no go, and RT]) for Model (1) Multiple linear regression model used to test the relationship between the independent variables (PFT (agility, static balance, dynamic balance and CMJ), MC components (BB, JS, MS, EHC), PFT, MCT and dependent variables (IC components (AC go, AC no go and RT) for Model (2) Model 1 is tested without any adjustments and Model 2 is adjusted for age, sex, and BMI. A total of 30 regression models were tested.

For categorical regression analysis, independent variables such as PF components (agility, static balance, dynamic balance, and CMJ) and MC components (BB, JS, MS, and EHC) were divided into tertiles (T1–T3), with T1 representing the lowest tertile. The relationships between these independent variables and IC were assessed.

PFT and MCT were categorized into tertiles. Categorization into tertiles (T1–T3) was used for analysis, where T1 represented the lowest tertile. The relationships between tertiles, continuous variables, and IC were examined. The results demonstrated that PFT, MCT, and their components were significantly associated with AC and RT after adjusting for age, sex, and BMI. PFT, MCT, and their four components showed a relationship between AC and RT after adjusting for age, sex, and BMI. Additionally, pairwise linear regression was used to test for nonlinear relationships and threshold effects between PFT, MCT, and IC. Statistical significance was set at $p < 0.05$.

Results

Participant characteristics

A total of 139 preschool children (78 boys, 61 girls) were included in the statistical analysis. The average age of the boys and girls was similar (Table 1). Boys had a slightly greater average height (114.45 ± 4.70 cm) than girls (113.07 ± 5.07 cm). The mean weight was 21.41 ± 3.58 kg for boys and 20.44 ± 3.89 kg for girls, with an overall average of 20.99 ± 3.74 kg.

Physical fitness (PF) indicators

Among the PF indicators, only static balance was significantly higher in girls than in boys ($p = 0.018$) CMJ were not significantly different, with boys averaging 19.46 ± 3.97 cm and girls 18.91 ± 3.11 cm ($p = 0.375$) and agility was comparable between boys and girls, resulting in an overall mean of 9.47 ± 0.92 s ($p = 0.247$).

Motor competence (MC) tasks

Significant differences were found in BB and EHC tasks. Girls performed better in BB (25.93 ± 9.59) than boys (21.31 ± 9.60) ($p = 0.006$). In EHC, boys achieved higher scores (4.96 ± 6.61) than girls (3.13 ± 2.70) ($p = 0.028$). No significant differences were observed in the JS and MS tasks.

Inhibitory control (IC) tasks

For IC tasks, significant differences were found in “No Go” accuracy, where girls scored higher than boys (12.15 ± 2.38 vs. 10.06 ± 3.33, $p < 0.001$). Reaction times were also significantly different, with girls having longer RTs (889.51 ± 83.63 ms) than boys (857.35 ± 75.57 ms) ($p = 0.019$). Accuracy in “go” trials showed no significant differences between groups ($p = 0.946$).

PFT and MCT scores

The PFT and MCT score did not differ significantly between boys and girls, with combined averages of 200.00 ± 20.12 and 200.00 ± 20.31, respectively (PFT: $p = 0.128$; MCT: $p = 0.399$). The detailed values of these variables are presented in Table 1.

Association between physical fitness, motor competence and inhibitory control

There was a positive association between static balance and AC (Go) (β = 0.086, 95% CI: 0.017, 0.156), BB and AC (Go) (β = 0.139, 95% CI: 0.056, 0.222), BB and AC (No Go) (β = 0.076, 95% CI:, 0.024, 0.128), JS and AC (Go) (β = 0.282, 95% CI: 0.177, 0.387), MS and AC (Go) (β = 0.311, 95% CI: 0.162, 0.460), MCT and AC (Go) (β = 0.079, 95% CI: 0.051, 0.107), MCT and AC (No Go) (β = 0.022, 95% CI: 0.003, 0.041).

However, there was a negative relationship between the agility and AC (Go) (β=-1.981, 95% CI: -2.838, -1.125), JS and RT (β=-3.262, 95% CI: -5.033, -1.492), MCT and RT (β=-0.497, 95% CI: -0.988, -0.006) and also static balance had a negative relationship with RT (β=-1.328, 95% CI: -2.468, -0.188) only after adjustment. After adjusting for age, sex, and BMI, the relationship between BB and AC (Go) (β = 0.146, 95% CI: 0.059, 0.234), JS and AC (Go) (β = 0.297, 95% CI: 0.186, 0.407), MCT and AC (Go) (β = 0.085, 95% CI: 0.056–0.115) improved, whereas the relationship between agility and AC (Go) (β=-2.180, 95% CI: -3.098, -1.261), BB, and AC (No Go) (β = 0.058, 95%

Table 1 Descriptive data on Anthropometric, Physical Fitness and Motor competence characteristics by gender

Characteristics	Boys ($n = 78$) ($\bar{x}$± Sd)	Girls ($n = 61$) ($\bar{x}$± Sd)	Total ($n = 139$) ($\bar{x}$± Sd)
Anthropometric Characteristics			
Age (years)	5.76 ± 0.30	5.75 ± 0.30	6 ± 1
Height (cm)	114.45 ± 4.70	113.07 ± 5.07	113.84 ± 4.9
Weight (kg)	21.41 ± 3.58	20.44 ± 3.89	20.99 ± 3.74
Body Composition			
BMI (kg/m2)	16.31 ± 1.88	15.95 ± 2.02	16.15 ± 1.94
Physical Fitness			
Agility (s)	9.39 ± 0.97	9.58 ± 0.85	9.47 ± 0.92
Static Balance (%)	75.03 ± 11.34	79.82 ± 12.20	77.13 ± 11.93
Dynamic Balance (%)	67.81 ± 16.17	68.95 ± 13.48	68.31 ± 15.01
CMJ (cm)	19.46 ± 3.97	18.91 ± 3.11	19.22 ± 3.62
Motor Competence			
BB (n)	21.31 ± 9.60	25.93 ± 9.59	28.34 ± 9.83
JS (n)	26.25 ± 7.44	27.41 ± 7.21	36.76 ± 7.34
MS (n)	25.37 ± 5.30	25.97 ± 5.45	25.63 ± 5.35
EHC (n)	4.96 ± 6.61	3.13 ± 2.70	4.16 ± 5.32
IC			
AC (go) (n)	56.27 ± 5.57	56.33 ± 4.25	56.29 ± 5.02
AC (no go) (n)	10.06 ± 3.33	12.15 ± 2.38	10.98 ± 3.12
RT (ms)	857.35 ± 75.57	889.51 ± 83.63	871.47 ± 80.52
PFT	197.70 ± 20.39	202.94 ± 19.53	200.00 ± 20.12
MCT	198.27 ± 29.17	202.22 ± 19.80	200.00 ± 20.31

Abbreviations: CMJ: Countermovement jump; BB: backward balancing; MS: moving sideways; JS: jumping sideways; EHC: eye–hand coordination; IC: inhibitory control; PFT: physical fitness T–score; MCT: motor competence T–score; AC: Accuracy number; RT: Reaction Time. Bold font indicates significant differences

CI: 0.005, 0.110) did not improve. There was no statistically significant relationship between PFT and IC variables (Table 2).

For categorical linear regression, independent variables were divided into three groups (T1 to T3, where T1 was the lowest) as shown in Table 3. For categorical linear regression, independent MCT was After adjusting confounders, compared with T1 group, the relationship between MCT of T2 group and AC (Go) improved to 3.356 (β = 3.536, 95% CI: 1.547, 5.525), and between MCT of T3 and AC (Go) to 3.776 (β = 3.776, 95% CI: 1.726, 5.826).

There is no significant relationship between PFT and IC variables and also pairwise linear regression model does not provide significant threshold to differentiate a certain point. Between the MCT and IC indicators, only AC (Go) has significant explanatory power.

The pairwise linear regression analysis revealed a nonlinear relationship between MCT and AC, as depicted in Fig. 2. The threshold value of 177.321 was determined using a segmented regression analysis with breakpoint estimation, which identified the point at which the relationship between MCT and AC transitioned from positive to non-significant. This approach enabled precise identification of the threshold and supported the interpretation of nonlinear relationships. For participants with MCT scores below 177.321, a significant positive relationship was observed with a beta coefficient of 0.286, suggesting that AC increased as MCT scores increased in this range. Upon adjusting for potential confounding variables such as sex, age, and BMI, the relationship remained significant. Specifically, for every 1-point increase in MCT, AC increased by 0.309, with a 95% confidence interval of 0.181 to 0.436. This adjustment underscores the robustness of the relationship between the MCT and AC (Go).

Table 4 showed that both Model 1 and Model 2 demonstrated significant overall explanatory power, with R squared values of 0.29 and 0.30, respectively. The likelihood ratio indicated a significant threshold effect on the relationship between MCT and AC (Go).

Discussion

This study aimed to explore the relationships between PF, MC, and IC in preschool children. Significant associations were observed between the MCT scores and IC indicators. Specifically, higher MCT scores were positively associated with better AC (Go) and AC (No Go). After adjusting for confounding factors, such as age, sex, and BMI, these associations remained robust. In addition, MCT scores were negatively associated with better RT. There was no statistically significant relationship between PFT and IC variables. Among the indicators of PF, agility had a negative relationship with AC (Go), while

Table 2 Association between physical fitness, motor competence and inhibitory control in preschool children

Variables	Accuracy number (AC of "Go")		Accuracy number (AC of "No Go" test)		Reaction time (RT)	
	ß (95%CI)		ß (95%CI)		ß (95%CI)	
	Model 1	**Model 2**	**Model 1**	**Model 2**	**Model 1**	**Model 2**
Physical Fitness						
Agility (s)	**-1.981 (-2.838, -1.125)**	**-2.180 (-3.098, -1.261)**	-0.053 (0.625, 0.520)	-0.169 (-0.750, 0.411)	7.871 (-6.832, 22.575)	2.585 (-12.792, 17.961)
	$p=0.000$, **$R^2=0.132$**	$p=0.000$, **$R^2=0.143$**	$p=0.856$, $R^2=0.000$	$p=0.565$, $R^2=0.116$	$p=0.292$, $R^2=0.008$	$p=0.740$, $R^2=0.068$
Static Balance (%)	**0.086 (0.017, 0.156)**	0.092 (0.018, 0.165)	0.027 (-0.017, 0.071)	0.013 (-0.031, 0.057)	-1.064 (-2.192, 0.062)	**-1.328 (-2.468, -0.188)**
	$p=0.015$, **$R^2=0.035$**	$p=0.177$, $R^2=0.046$	$p=0.233$, $R^2=0.010$	$p=0.552$, $R^2=0.116$	$p=0.064$, $R^2=0.025$	$p=0.005$, **$R^2=0.103$**
Dynamic Balance (%)	0.04 (-0.16, 0.096)	0.039 (-0.020, 0.099)	-0.04 (-0.039, 0.031)	-0.004 (-0.031, 0.039)	-0.455 (-1.358, 0.448)	-0.289 (-1.214, 0.615)
	$p=0.162$, $R^2=0.140$	$p=0.733$, $R^2=0.015$	$p=0.827$, $R^2=0.000$	$p=0.806$, $R^2=0.114$	$p=0.321$, $R^2=0.007$	$p=0.537$, $R^2=0.070$
CMJ (cm)	0.204 (-0.028, 0.436)	0.210 (-0.026, 0.455)	-0.025 (-0.171, 0.121)	0.001 (-0.139, 0.141)	-2.384 (-6.122, 1.353)	-2.162 (-5.844, 1.521)
	$p=0.084$, $R^2=0.022$	$p=0.499$, $R^2=0.025$	$p=0.737$, $R^2=0.001$	$p=0.991$, $R^2=0.114$	$p=0.209$, $R^2=0.011$	$p=0.248$, $R^2=0.077$
Motor Competence						
BB (n)	**0.139 (0.056, 0.222)**	**0.146 (0.059, 0.234)**	**0.076 (0.024, 0.128)**	**0.058 (0.005, 0.110)**	0.627 (-0.752, 2.006)	0.462 (-0.941, 1.866)
	$p=0.001$, **$R^2=0.074$**	$p=0.027$, **$R^2=0.078$**	$p=0.005$, **$R^2=0.057$**	$p=0.000$, **$R^2=0.144$**	$p=0.370$, $R^2=0.006$	$p=0.516$, $R^2=0.070$
JS (n)	**0.282 (0.177, 0.387)**	**0.297 (0.186, 0.407)**	0.045 (-0.027, 0.116)	0.040 (-0.031, 0.111)	**-3.262 (-5.033, -1.492)**	**-3.195 (-4.999, -1.391)**
	$p=0.000$, **$R^2=0.170$**	$p=0.000$, **$R^2=0.176$**	$p=0.218$, $R^2=0.011$	$p=0.269$, $R^2=0.122$	$p=0.000$, **$R^2=0.088$**	$p=0.000$, **$R^2=0.146$**
MS (n)	**0.311 (0.162, 0.460)**	**0.323 (0.167, 0.480)**	0.079 (-0.019, 0.176)	0.076 (-0.020, 0.173)	-1.780 (-4.302, 0.742)	-1.382 (-3.949, 1.186)
	$p=0.000$, **$R^2=0.110$**	$p=0.003$, **$R^2=0.112$**	$p=0.113$, $R^2=0.018$	$p=0.120$, $R^2=0.129$	$p=0.165$, $R^2=0.014$	$p=0.289$, $R^2=0.075$
EHC (n)	0.154 (-0.003, 0.311)	0.162 (-0.005, 0.328)	0.023 (-0.076, 0.122)	0.059 (-0.040, 0.157)	-1.841 (-4.377, 0.694)	-0.956 (-3.570, 1.658)
	$p=0.055$, $R^2=0.027$	$p=0.413$, $R^2=0.029$	$p=0.649$, $R^2=0.002$	$p=0.240$, $R^2=0.123$	$p=0.153$, $R^2=0.015$	$p=0.471$, $R^2=0.071$
PFT	0.013 (-0.029, 0.055)	0.015 (-0.030, 0.060)	0.003 (-0.023, 0.029)	-0.001 (-0.028, 0.025)	-0.516 (-1.187, 0.154)	-0.670 (-1.360, 0.021)
	$p=0.531$, $R^2=0.003$	$p=0.952$, $R^2=0.005$	$p=0.822$, $R^2=0.000$	$p=0.920$, $R^2=0.114$	$p=0.130$, $R^2=0.017$	$p=0.057$, $R^2=0.092$
MCT	**0.079 (0.051, 0.107)**	**0.085 (0.056,3 0.115)**	**0.022 (0.003, 0.041)**	**0.022 (0.003, 0.041)**	**-0.497 (-0.988, -0.006)**	-0.432 (-0.940, 0.076)
	$p=0.000$, **$R^2=0.187$**	$p=0.000$, **$R^2=0.196$**	$p=0.025$, **$R^2=0.036$**	$p=0.000$, **$R^2=0.146$**	$p=0.047$, **$R^2=0.028$**	$p=0.095$, $R^2=0.087$

Abbreviations: IC, inhibitory control; BB, backward balancing; MS, moving sideways; JS, jumping sideways; EHC, eye–hand coordination; PFT, physical fitness T–score; MCT, motor competence T–score. Bold font indicates significant differences static balance was positively associated with RT and negatively associated with AC (Go). Additionally, among the indicators of MC, BB, JS, and MS had a positive correlation with AC (Go) and JS had a negative relationship with RT. There was a positive association between the MCT-score and AC (Go) or AC (No Go). However, there was a negative relationship between the MCT-score and RT. One of the interesting findings obtained in this study was the determination of the threshold for motor proficiency of 177.32. An MC score higher than this value does not lead to a change in AC (Go) levels, whereas a MC level below 177.32 causes an increase in AC (Go).

It has been reported that EF in children between the ages of 3 and 6 years of age are described as a single, unified component reflecting general cognitive skills [17, 53]. However, after the preschool period, EF seem to start to decompose markedly into factors such as working memory, cognitive flexibility and IC [54]. This suggests that the developmental trajectory of EF is complex and evolves over time from general capacity to more specialized functions [17, 53–55]. Liu et al. [31] observed a significant negative correlation between motor skills and RT of IC in preschool children, emphasizing the interdependence of motor and cognitive development. In addition, a significant and moderate correlation was found between MC and EF [7]. Cook et al. [29] also reported that motor skills were positively correlated with EFs, especially with IC. Our results are partially consistent with those of the previous studies.

Moreover, it is essential to consider the possibility of improving the MC development in children. Infant motor development is positively and significantly correlated with EF performance in healthy adults [56]. Therefore, it is also possible to speculate that physiological and learning/developmental mechanisms have an indirect effect on MC and EF [57, 58]. In this regard, higher levels of motor skill competence offer a greater motor repertoire to engage in physical activities and sports [59], and consequently contribute to the development of EF [7]. At this point, the results obtained in the research also suggest that they may be attributed to the gains children acquire from participating in physical activity. It has been highlighted that having an MCT-score higher than 177.32 did not lead to a change in IC indicators in the study. Therefore, establishing this score as a reference for the assessment of MC in preschool children may be appropriate. However, it should be noted that further research is still needed in this regard to draw more conclusive findings.

The findings of the study conducted by Li et al. [26] showed a negative relationship between PFT scores in preschool children and RT, an inhibition parameter. Other studies also indicate that higher PF during the preschool period is associated with better RT performance [51, 60]. However, these findings are not completely aligned with those of our study, which demonstrated that only agility had a negative relationship with and RT, and static balance levels also had a positive relationship with AC (Go). The differences between the findings of our study and those of Li et al. [26], as well as other studies [51, 60], could be attributed to several factors, such as differences in study design, sample characteristics, and the specific physical fitness components assessed.

In this study, no relationship was found between the inhibition parameters of dynamic balance and CMJ, which are considered PF parameters. The lack of a significant association between PF and IC, apart from the positive association with static balance, may stem from several factors. It is possible that the components of PF measured in this study were not directly aligned with the cognitive demands of IC tasks. As a component of PF, static balance may have a stronger connection to IC tasks because it requires sustained focus, motor coordination, and postural control, which are closely tied to cognitive inhibitory processes. Consistent with these findings, previous research has also reported no significant relationship between the peak power of vertical jump and inhibition parameters [23, 26]. However, a study conducted in rural areas of China found a relationship between muscle strength and EF in children and adolescents. Furthermore, individuals with higher muscle strength exhibit shorter executive function reaction times and a lower risk of developing EF disorders [32]. Generally, the results obtained from various studies suggest a linear relationship between physical activity and PF [61, 62]. Moreover, engaging in more frequent and regular physical activity has been shown to positively impact EF [63, 64].

Strengths and limitations

This study has several strengths. First, we evaluated PF and MC, and performed a comprehensive assessment using standardized scores to determine the relationship between these elements and inhibition parameters. Second, we employed multiple linear regression and pairwise linear regression to uncover the nonlinear relationship between PF and IC. However, this study had some limitations. The use of a cross-sectional study design and relatively small sample size are limitations, indicating the need for larger sample sizes and longitudinal studies in the future to confirm the relationships between PF, MC, and IC. The sampling strategy and representativeness of the preschool-aged study sample should also be considered, as this could affect the generalizability of the results. Third, despite controlling for known potential confounding factors, the level of physical activity should also be considered and controlled for in future research. Finally, another limitation of this study is that the T-scores calculated in this study are sample-specific

Table 3 Association between physical fitness, motor competence and inhibitory control in preschool children (categorical regression)

Variables	Accuracy number (AC of "Go")		Accuracy number (AC of "No Go" test)		Reaction time (RT)	
	ß (95%CI)		ß (95%CI)		ß (95%CI)	
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
Physical Fitness						
Agility (s)						
T1 (7.88-9.00)	REF.	REF.	REF.	REF.	REF.	REF.
T2 (9.02–9.752)	-0.547 (-2.520, 1.427)	-0.613 (-2.638, 1.413)	1.092 (-0.189, 2.374)	0.938 (-0.302, 2.179)	8.389 (-25.003, 41.782)	0.445 (-32.844, 33.734)
T3 (9.77–13.58)	**-3.638 (-5.590, -1.687)***	**-3.913 (-5.986, -1.839)**	0.149 (-1.119, 1.416)	−0.206 (-1.476, 1.064)	11.662 (-21.365, 44.690)	-1.528 (-35.605, 32.549)
	p = 0.001, **R^2=0.104**	p = 0.008, **R^2=0.111***	p = 0.194, R^2=0.024	p = 0.001, **R^2=0.138**	p = 0.772, R^2=0.004	p = 0.094, R^2=0.068
Static Balance (%)						
T1 (30.00–74.00)	REF.	REF.	REF.	REF.	REF.	REF.
T2 (75.00-84.40)	1.661 (-0.373, 3.695)	2.044 (-0.157, 4.244)	**1.608 (0.340, 2.876)****	1.150 (-0.160, 2.460)	6.194 (-26.792, 39.139)	-10.151 (-44.623, 24.322)
T3 (85.00–93.00)	**2.617 (0.605, 4.629)***	2.856 (0.729, 4.984)	0.851 (-0.403, 2.105)	0.393 (-0.874, 1.659)	-24.806 (-57.431, 7.819)	**-34.767 (-68.098, -1.437)****
	p = 0.037, **R^2=0,047**	p = 0.188, R^2=0.054	p = 0.046, R^2=0.044	p = 0.002, **R^2=0.134**	p = 0.146, R^2=0.028	p = 0.016, **R^2=0.099**
Dynamic Balance (%)						
T1 (26.00–63.00)	REF.	REF.	REF.	REF.	REF.	REF.
T2 (64.00–75.00)	-0.650 (-2.710, 1.410)	-0.752 (-2.881, 1.376)	0.064 (-1.226, 1.354)	0.103 (-1.154, 1.360)	-17.854 (-50.963, 15.254)	-12.107 (-45.284, 21.069)
T3 (76.00–97.00)	0.772 (-1.276, 2.820)	0.669 (-1.478, 2.815)	-0.002 (-1.285, 1.281)	0.098 (-1.169, 1.365)	-16.837 (-49.760, 16.085)	-10.015 (-43.472, 23.441)
	p = 0.403, R^2=0.013	p = 0.840, R^2=0.015	p = 0.994, R^2=0.000	p = 0.006, **R^2=0.114**	p = 0.485, R^2=0.011	p = 0.076, R^2=0.072
CMJ (cm)						
T1 (7.00-17.32)	REF.	REF.	REF.	REF.	REF.	REF.
T2 (17.40-20.98)	0.261 (-1.813, 2.335)	0.270 (-1.835, 2.376)	-0.109 (-1.404, 1.187)	0.061 (-1.180, 1.301)	4.583 (-28.179, 37.346)	7.089 (-25.149, 39.327)
T3 (21.00-27.20)	1.131 (-0.931, 3.194)	1.139 (-0.967, 3.246)	-0.343 (-1.632, 0.945)	-0.054 (-1.296, 1.187)	-31.640 (-64.228, 0.948)	-26.882 (-59.140, 5.376)
	p = 0.525, R^2=0.009	p = 0.907, R^2=0.011	p = 0.865, R^2=0.002	p = 0.006, **R^2=0.114**	p = 0.060, R^2=0.041	p = 0.014, **R^2=0.101**
Motor Competence						
BB (n)						
T1 (2.00–19.00)	REF.	REF.	REF.	REF.	REF.	REF.
T2 (20.00–26.00)	**2.707 (0.722, 4.691)***	2.854 (0.812, 4.896)	**1.317 (0.093, 2.541)****	0.911 (-0.293, 2.115)	**34.969 (2.579, 67.358)****	27.726 (-4.639, 60.091)
T3 (27.00–56.00)	**2.995 (1.011, 4.980)***	3.102 (1.022, 5.182)	**2.273 (1.049, 3.497)***	**1.925 (0.699, 3.151)***	**35.210 (2.820, 67.599)****	**35.482 (2.514, 68.450)****
	p = 0.005, **R^2=0.075**	p = 0.051, R^2=0.079	p = 0.001, **R^2=0.091**	p = 0.000, **R^2=0.173**	p = 0.048, **R^2=0.044**	p = 0.013, **R^2=0.102**
JS (n)						
T1 (2.00–24.00)	REF.	REF.	REF.	REF.	REF.	REF.
T2 (25.00–29.00)	1.034 (-0.929, 2.997)	1.036 (-0.960, 3.032)	0.119 (-1.147, 1.385)	0.182 (-1.033, 1.398)	**-51.153 (-82.280, -20.025)***	**-48.554 (-79.183, -17.925)***
T3 (30.00–55.00)	**3.358 (1.371, 5.344)***	3.406 (1.348, 5.465)	0.693 (-0.588, 1.975)	0.524 (-0.729, 1.777)	**-54.009 (-85.518, -22.449)***	**-53.188 (-84.772, -21.603)***
	p = 0.004, **R^2=0.078**	p = 0.051, R^2=0.079	p = 0.533, R^2=0.009	p = 0.005, **R^2=0.118**	p = 0.001, **R^2=0.100**	p = 0.000, **R^2=0.158**
MS (n)						
T1 (11.00–23.00)	REF.	REF.	REF.	REF.	REF.	REF.
T2 (24.00–28.00)	**2.195 (0.252, 4.138)****	**2.391 (0.343, 4.439)****	0.006 (-1.239, 1.251)	-0.246 (-1.483, 0.991)	-12.485 (-45.123, 20.153)	-10.437 (-43.744, 22.870)
T3 (29.00–38.00)	**3.610 (1.641, 5.578)***	**3.801 (1.727, 5.876)***	1.296 (0.035, 2.557)	1.110 (-0.143, 2.363)	-9.859 (-42.919, 23.200)	-6.328 (-40.061, 27.405)
	p = 0.002, **R^2=0.091**	p = 0.021, **R^2=0.094**	p = 0.080, R^2=0.036	p = 0.001, **R^2=0.147**	p = 0.723, R^2=0.005	p = 0.082, R^2=0.070

Table 3 (continued)

Variables	Accuracy number (AC of "Go")		Accuracy number (AC of "No Go" test)		Reaction time (RT)	
	ß (95%CI)		ß (95%CI)		ß (95%CI)	
	Model 1	**Model 2**	**Model 1**	**Model 2**	**Model 1**	**Model 2**
EHC (n)						
T1 (0.00–2.00)	REF.	REF.	REF.	REF.	REF.	REF.
T2 (2.01-3.00)	**2.823 (0.330, 5.316)****	2.938 (0.403, 5.473)	0.379 (-1.224, 1.981)	0.691 (-0.837, 2.220)	-22.445 (-63.568, 18.679)	-19.971 (-60.630, 20.687)
T3 (3.01-39.00)	**2.767 (0.839, 4.696)***	2.919 (0.883, 4.955)	0.782 (-0.458, 2.021)	1.057 (-0.170, 2.285)	-25.265 (-57.076, 6.545)	-17.782 (-50.439, 14.874)
	$p=0.006$, **R^2=0.073**	$p=0.053$, R^2=0.079	$p=0.453$, R^2=0.012	$p=0.002$, **R^2=0.134**	$p=0.224$, R^2=0.022	$p=0.049$, **R^2=0.079**
PFT						
T1 (141.15-192.72)	REF.	REF.	REF.	REF.	REF.	REF.
T2 (192.86-209.41)	0.696 (-1.385, 2.778)	0.746 (-1.385, 2.877)	-0.283 (-1.577, 1.011)	-0.649 (-1.895, 0.597)	-28.146 (-60.933, 4.641)	**-37.375 (-69.529, -5.220)****
T3 (209.90-244.14)	0.449 (-1.621, 2.518)	0.438 (-1.728, 2.605)	0.213 (-1.074, 1.500)	-0.029 (-1.296, 1.237)	-37.318 (-69.930, -4.706)	**-43.480 (-76.164, -10.797)****
	$p=0.799$, R^2=0.003	$p=0.979$, R^2=0.06	$p=0.748$, R^2=0.004	$p=0.004$, **R^2=0123**	$p=0.066$, R^2=0.039	$p=0.004$, R^2=0.121
MCT						
T1 (120.30-192.74)	REF.	REF.	REF.	REF.	REF.	REF.
T2 (193.39-209.41)	**3.500 (1.539, 5.461)***	**3.536 (1.547, 5.525)***	0.652 (-0.631, 1.935)	0.742 (-0.484, 1.968)	-6.007 (-38.807, 26.793)	-3.724 (-35.986, 28.539)
T3 (209.86-286.55)	**3.683 (1.733, 5.633)***	**3.776 (1.726, 5.826)***	1.098 (-0.178, 2.374)	1.054 (-0.209, 2.318)	-35.817 (-68.443, -3.192)	-32.319 (-65.571, 0.933)
	$p=0.000$, **R^2=0.115**	$p=0.005$, **R^2=0.116**	$p=0.235$, R^2=0.021	$p=0.002$, **R^2=0.132**	$p=0.070$, R^2=0.038	$p=0.017$, **R^2=0.097**

Abbreviations: IC, inhibitory control; BB, backward balancing; MS, moving sideways; JS, jumping sideways; EHC, eye−hand coordination; PFT, physical fitness T−score; MCT, motor competence T−score. Bold font indicates significant differences. *p<0.001, **p=<0.005

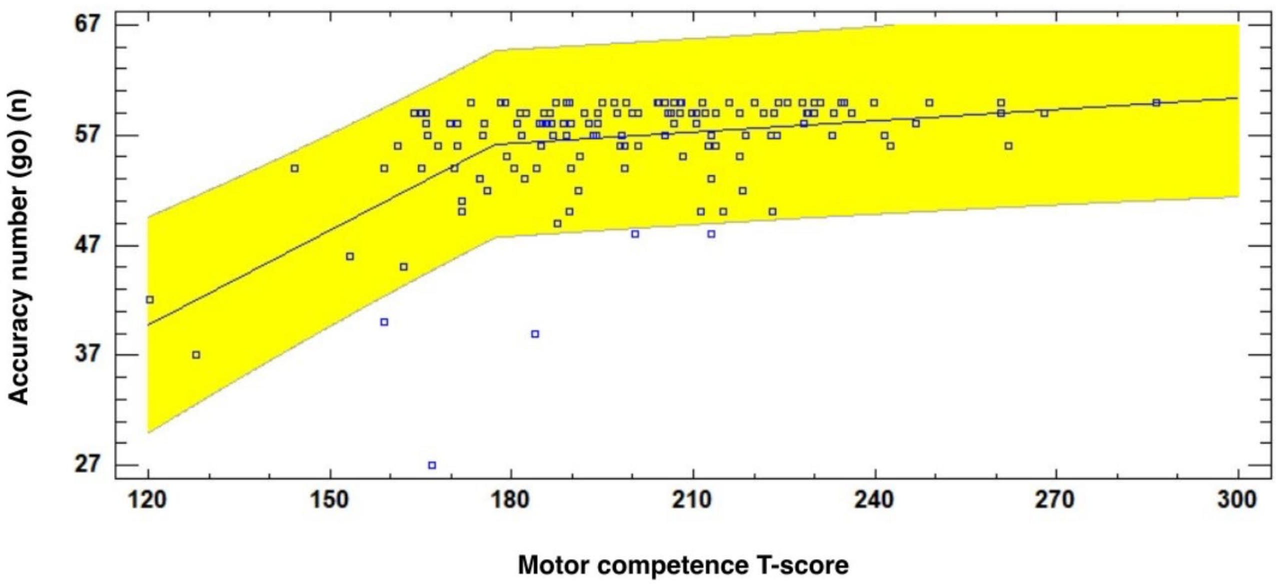

Fig. 2 Relationship between MCT and IC– pairwise linear regression

Table 4 Threshold effect analysis between MCT and AC

MCT	AC (Go) ß (95%CI)	
	Model 1	Model 2
≤ 177.321	**0.286 (0.163, 0.409)**	**0.309 (0.181, 0.436)**
> 177.321	0.034 (-0.002, 0.070)	0.035 (-0.003, 0.074)
R squared	0.29	0.30
Likelihood Ratio	< 0.001	< 0.001

Abbreviations: AC, Accuracy; MCT, Motor Competence T–score. Bold font indicates significant differences. Model 2 adjusted for age, sex and BMI

and were derived from a specific cohort. This limits their application for international comparisons. Researchers should approach the use of these cut-off scores cautiously across diverse populations, considering potential differences in cultural, environmental, and socio-economic factors. Future research should aim to establish universal standards to enable more reliable comparisons across populations. The application of such cut-off across different populations should be approached with caution due to potential differences in cultural, environmental, and socio-economic factors. Further research is needed to establish universal standards that can enable more reliable comparisons across diverse populations.

Conclusions

In summary, no relationship was found between PFT and IC indicators in preschool children. However, specific PF components, namely agility and static balance, were positively associated with IC indicators—agility with AC (Go) and static balance was negatively associated with RT. Furthermore, JS, and static balance were negatively associated with RT, highlighting potential complexities in the interplay between MC and PF and IC. In contrast, significant associations were observed between overall MCT scores and IC indicators, with lower MCT scores (≤ 177.32) linked to higher AC (Go) scores. These findings highlight the potential importance of MC in supporting IC and executive function development. While these results emphasize the critical role of MC, the lack of consistent relationships between overall PF scores and IC indicators suggests domain-specific effects that warrant further investigation. The observational design of this study limits causal interpretations. Therefore, future longitudinal studies and intervention-based research are required to confirm and expand upon these relationships, particularly to clarify how PF and MC contribute to executive function in early childhood.

Abbreviations

AC	Accuracy
BB	Backward balancing
BMI	Body mass index
CMJ	Counter movement jump(ing)
EF	Executive functions
EF	Executive functions
EHC	Eye-hand coordination
IC	Inhibitory control
JS	Sideways jumping
KTK	Körperkoordinationstest für Kinder

MS Sideways movement
MC Motor competence
MCT Motor competence T-score
PF Physical fitness
PFT Physical fitness T-score
RT Reaction time

Acknowledgements
This research was funded by Princess Nourah bint Abdulrahman University Researchers Supporting Project number (PNURSP2025R286), Princess Nourah bint Abdulrahman University, Riyadh, Saudi Arabia.

Author contributions
Conceptualization, U.C., A.G., S.B., M.D., A.M.S., G.Y., M.I.A.; methodology, U.C., A.G.; Data analysis, U.C., A.G writing—original draft preparation, U.C., A.G.,S.B.,M.D, A.M.S.,G.Y.,M.I.A; writing—review and editing, U.C., A.G., S.B., M.D., A.M.S., G.Y., M.I.A. All authors have read and agreed to the published version of the manuscript.

Funding
This research was funded by Princess Nourah bint Abdulrahman University Researchers Supporting Project number (PNURSP2025R286), Princess Nourah bint Abdulrahman University, Riyadh, Saudi Arabia. The authors did not receive any funds, grants, or financial assistance from any organization for the submitted research.

Data availability
The datasets used in this study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate
The study was conducted in accordance with the Declaration of Helsinki and was reviewed and approved by the Ethics Committee of Tekirdag Namik Kemal University Faculty of Medicine (Research protocol number: 2022.214.11.15). Informed consent was obtained from all study participants was obtained from the parents or legal guardians prior to their participation.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

Received: 15 June 2024 / Accepted: 30 January 2025
Published online: 28 February 2025

References

1. Niendam TA, Laird AR, Ray KL, Dean YM, Glahn DC, Carter CS. Meta-analytic evidence for a superordinate cognitive control network subserving diverse executive functions. Cogn Affect Behav Neurosci. 2012;12:241–68.
2. Bailey BA, Andrzejewski SK, Greif SM, Svingos AM, Heaton SC. The role of executive functioning and academic achievement in the academic self-concept of children and adolescents referred for neuropsychological assessment. Children. 2018;5:83.
3. Diamond A. Executive functions. Annu Rev Psychol. 2013;64:135–68.
4. Medeiros W, Torro-Alves N, Malloy-Diniz LF, Minervino CM. Executive functions in children who experience bullying situations. Front Psychol. 2016;7:205853.
5. Diamond A, Ling DS. Conclusions about interventions, programs, and approaches for improving executive functions that appear justified and those that, despite much hype, do not. Dev Cogn Neurosci. 2016;18:34–48.
6. Dowsett SM, Livesey DJ. The development of inhibitory control in preschool children: effects of executive skills training. Dev Psychobiol. 2000;36:161–74.
7. Albuquerque MR, Rennó GVC, Bruzi AT, Fortes LDS, Malloy-Diniz LF. Association between motor competence and executive functions in children. Appl Neuropsychology: Child. 2022;11:495–503.
8. Ludyga S, Pühse U, Gerber M, Herrmann C. Core executive functions are selectively related to different facets of motor competence in preadolescent children. Eur J Sport Sci. 2019;19:375–83.
9. Van Damme T, Simons J, Sabbe B, Van West D. Motor abilities of children and adolescents with a psychiatric condition: a systematic literature review. World J Psychiatry. 2015;5:315.
10. Kaiser M-L, Schoemaker MM, Albaret J-M, Geuze RH. What is the evidence of impaired motor skills and motor control among children with attention deficit hyperactivity disorder (ADHD)? Systematic review of the literature. Res Dev Disabil. 2015;36:338–57.
11. Rigoli D, Piek JP, Kane R, Oosterlaan J. An examination of the relationship between motor coordination and executive functions in adolescents. Develop Med Child Neuro. 2012;54:1025–31.
12. Ke D, Maimaitijiang R, Shen S, Kishi H, Kurokawa Y, Suzuki K. Field-based physical fitness assessment in preschool children: a scoping review. Front Pead. 2022;10:939442.
13. Ortega FB, Ruiz JR, Castillo MJ, Sjöström M. Physical fitness in childhood and adolescence: a powerful marker of health. Int J Obes. 2008;32:1–11.
14. Tremblay MS, LeBlanc AG, Carson V, Choquette L, Connor Gorber S, Dillman C, et al. Canadian physical activity guidelines for the early years (aged 0–4 years). Appl Physiol Nutr Metab. 2012;37:345–56.
15. Brown WH, Pfeiffer KA, McIver KL, Dowda M, Addy CL, Pate RR. Social and environmental factors Associated with preschoolers' nonsedentary physical activity. Child Dev. 2009;80:45–58.
16. Reilly JJ. Low levels of objectively measured physical activity in preschoolers in child care. Med Sci Sports Exerc. 2010;42:502–7.
17. Hogan M, Kiefer M, Kubesch S, Collins P, Kilmartin L, Brosnan M. The interactive effects of physical fitness and acute aerobic exercise on electrophysiological coherence and cognitive performance in adolescents. Exp Brain Res. 2013;229:85–96.
18. Tomporowski PD, Davis CL, Miller PH, Naglieri JA. Exercise and children's intelligence, cognition, and academic achievement. Educ Psychol Rev. 2008;20:111–31.
19. Van Der Niet AG, Smith J, Scherder EJ, Oosterlaan J, Hartman E, Visscher C. Associations between daily physical activity and executive functioning in primary school-aged children. J Sci Med Sport. 2015;18:673–7.
20. Gärtner A, Strobel A. Individual differences in inhibitory control: a latent variable analysis. J Cognition. 2021;4:1–18.
21. Menu I, Rezende G, Le Stanc L, Borst G, Cachia A. Inhibitory control training on executive functions of children and adolescents: a latent change score model approach. Cogn Dev. 2022;64:101231.
22. Tu M, Yang F. Research Progress on executive function of Preschool Children abroad in recent ten years. Stud Early Child Educ. 2018;9:27–38.
23. Nieto-López M, Sánchez-López M, Visier-Alfonso ME, Martínez-Vizcaíno V, Jiménez-López E, Álvarez-Bueno C. Relation between physical fitness and executive function variables in a preschool sample. Pediatr Res. 2020;88:623–8.
24. Donnelly JE, Hillman CH, Castelli D, Etnier JL, Lee S, Tomporowski P, et al. Physical activity, fitness, cognitive function, and academic achievement in children: a systematic review. Med Sci Sports Exerc. 2016;48:1197–222.
25. Moffitt TE, Arseneault L, Belsky D, Dickson N, Hancox RJ, Harrington H, et al. A gradient of childhood self-control predicts health, wealth, and public safety. Proc Natl Acad Sci USA. 2011;108:2693–8.
26. Li Y, Zhou T, Lu Y, Sang M, Liu J, He X, et al. The association between the health-related physical fitness and inhibitory control in preschool children. BMC Pediatr. 2022;22:106.
27. Garon N, Bryson SE, Smith IM. Executive function in preschoolers: a review using an integrative framework. Psychol Bull. 2008;134:31.
28. Tomaz SA, Jones RA, Hinkley T, Bernstein SL, Twine R, Kahn K, et al. Gross motor skills of South African preschool-aged children across different income settings. J Sci Med Sport. 2019;22:689–94.
29. Cook CJ, Howard SJ, Scerif G, Twine R, Kahn K, Norris SA, et al. Associations of physical activity and gross motor skills with executive function in preschool children from low-income South African settings. Dev Sci. 2019;22:e12820.
30. Haapala EA. Cardiorespiratory fitness and motor skills in relation to cognition and academic performance in children–a review. J Hum Kinetics. 2013;36:55–68.
31. Liu J, Li Y, Zhou T, Lu Y, Sang M, Li L, et al. Relationship between Gross Motor skills and Inhibitory Control in Preschool children: a pilot study. Front Hum Neurosci. 2022;16:848230.

32. Zeng Q, Hu X, Wang Y. The association between muscle strength and executive function in children and adolescents: based on survey evidence in rural areas of China. Front Psychol. 2023;13:1090143.
33. Veraksa A, Tvardovskaya A, Gavrilova M, Yakupova V, Musálek M. Associations between executive functions and physical fitness in preschool children. Front Psychol. 2021;12:674746.
34. Champely S, pwr. Basic Functions for Power Analysis (R package version 1.3-0) [Computer software]. 2020.
35. Bosy-Westphal A, Later W, Hitze B, Sato T, Kossel E, Glüer C-C, et al. Accuracy of bioelectrical impedance consumer devices for measurement of body composition in comparison to whole body magnetic resonance imaging and dual X-ray absorptiometry. Obes Facts. 2008;1:319–24.
36. Howard SJ, Melhuish E. An early years toolbox for assessing early executive function, Language, Self-Regulation, and Social Development: validity, reliability, and preliminary norms. J Psychoeducational Assess. 2017;35:255–75.
37. Zelazo PD, Anderson JE, Richler J, Wallner-Allen K, Beaumont JL, Weintraub S. II. NIH toolbox cognition battery (CB): measuring executive function and attention. Monogr Soc Res Child. 2013;78:16–33.
38. Tulsky DS, Carlozzi NE, Chevalier N, Espy KA, Beaumont JL, Mungas D. V. NIH toolbox cognition battery (CB): measuring working memory. Monogr Soc Res Child. 2013;78:70–87.
39. Delaney T, Jackson JK, Jones J, Hall A, Dives A, Wedesweiler T, et al. A cluster randomised controlled trial of an intervention to increase physical activity of preschool-aged children attending early childhood education and care: study protocol for the 'everybody energise'trial. Int J Environ Res Public Health. 2019;16:4275.
40. Wiebe SA, Sheffield TD, Espy KA. Separating the Fish from the sharks: a longitudinal study of Preschool Response Inhibition. Child Dev. 2012;83:1245–61.
41. Howard SJ, Okely AD. Catching fish and avoiding sharks: investigating factors that influence developmentally appropriate measurement of preschoolers' Inhibitory Control. J Psychoeducational Assess. 2015;33:585–96.
42. McNeill J, Howard SJ, Vella SA, Santos R, Cliff DP. Physical activity and modified organized sport among preschool children: associations with cognitive and psychosocial health. Ment Health Phys Act. 2018;15:45–52.
43. Kiphard EJ, Schilling F. Körperkoordinationstest für Kinder: KTK; Manual. 2., überarb. u. erg. Aufl. Göttingen: Beltz Test; 2007.
44. Kiphard EJ, Schilling F. Körperkoordinationstest für kinder: KTK. Beltz; 1974.
45. Platvoet S, Faber IR, de Niet M, Kannekens R, Pion J, Elferink-Gemser MT, et al. Development of a tool to assess fundamental movement skills in applied settings. Front Educ. 2018;3:75.
46. Novak AR, Bennett KJ, Beavan A, Pion J, Spiteri T, Fransen J, et al. The applicability of a short form of the Körperkoordinationstest für Kinder for measuring motor competence in children aged 6 to 11 years. J Motor Learn Dev. 2017;5:227–39.
47. Fransen J, D'Hondt E, Bourgois J, Vaeyens R, Philippaerts RM, Lenoir M. Motor competence assessment in children: convergent and discriminant validity between the BOT-2 short form and KTK testing batteries. Res Dev Disabil. 2014;35:1375–83.
48. Coppens E, Laureys F, Mostaert M, D'Hondt E, Deconinck FJA, Lenoir M. Validation of a motor competence Assessment Tool for children and adolescents (KTK3+) with normative values for 6- to 19-Year-Olds. Front Physiol. 2021;12:652952.
49. Canli T, Canli U, Taskin C, Aldhahi MI. Motor Coordination in Primary School students: the role of Age, Sex, and physical activity participation in Turkey. Children. 2023;10:1524.
50. Liviu M, Ilie M, Fernando G. Determination of balance parameters as physical training factors in Athletics. J Phys Educ Sport. 2018;18:2054.
51. Vescovi JD, Mcguigan MR. Relationships between sprinting, agility, and jump ability in female athletes. J Sports Sci. 2008;26:97–107.
52. Markovic G, Dizdar D, Jukic I, Cardinale M. Reliability and factorial validity of squat and countermovement jump tests. J Strength Conditioning Res. 2004;18:551–5.
53. Wiebe SA, Sheffield T, Nelson JM, Clark CA, Chevalier N, Espy KA. The structure of executive function in 3-year-olds. J Exp Child Psychol. 2011;108:436–52.
54. Messer D, Bernardi M, Botting N, Hill EL, Nash G, Leonard HC, et al. An exploration of the factor structure of executive functioning in children. Front Psychol. 2018;9:1179.
55. Brocki KC, Bohlin G. Executive functions in children aged 6 to 13: a dimensional and developmental study. Dev Neuropsychol. 2004;26:571–93.
56. Ridler K, Veijola JM, Tanskanen P, Miettunen J, Chitnis X, Suckling J, et al. Fronto-cerebellar systems are associated with infant motor and adult executive functions in healthy adults but not in schizophrenia. Proc Natl Acad Sci USA. 2006;103:15651–6.
57. Sibley BA, Etnier JL. The relationship between physical activity and cognition in children: a meta-analysis. Pediatr Exerc Sci. 2003;15:243–56.
58. Piek JP, Dyck MJ, Nieman A, Anderson M, Hay D, Smith LM, et al. The relationship between motor coordination, executive functioning and attention in school aged children. Arch Clin Neuropsychol. 2004;19:1063–76.
59. Stodden DF, Goodway JD, Langendorfer SJ, Roberton MA, Rudisill ME, Garcia C, et al. A developmental perspective on the role of Motor Skill competence in physical activity: an Emergent Relationship. Quest. 2008;60:290–306.
60. Chang Y-K, Tsai Y-J, Chen T-T, Hung T-M. The impacts of coordinative exercise on executive function in kindergarten children: an ERP study. Exp Brain Res. 2013;225:187–96.
61. Janssen I, LeBlanc AG. Systematic review of the health benefits of physical activity and fitness in school-aged children and youth. Int J Behav Nutr Phys Act. 2010;40:1–16.
62. Kemper HCG, De Vente W, Van Mechelen W, Twisk JWR. Adolescent motor skill and performance: is physical activity in adolescence related to adult physical fitness? Am J Hum Biol. 2001;13:180–9.
63. Best JR. Effects of physical activity on children's executive function: contributions of experimental research on aerobic exercise. Dev Rev. 2010;30:331–51.
64. Mao F, Huang F, Zhao S, Fang Q. Effects of cognitively engaging physical activity interventions on executive function in children and adolescents: a systematic review and meta-analysis. Front Psychol. 2024;15:1454447.

Publisher's note