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Executive function skills predict motor competence in preschool children

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Abstract

Background Motor competence and executive function skills develop actively at preschool age. Both are important for socialization, school achievements, and well-being. However, the association between motor competence and executive functions has not yet been fully investigated in preschool children. This study aimed to explore which executive function skills may be predictors of motor competence and its components.

Methods Two hundred seventy-two typically developing 5- to 6-year-old children (46% girls) participated in this study. The motor competence assessment tool 'Movement Assessment Battery for Children-2' was used on the Russian sample for the first time.

Results The study revealed that higher motor inhibition, working memory, and age were significant predictors of higher motor competence, manual dexterity, and balance skills. Higher aiming and catching skills were predicted only by higher motor inhibition and age. The study also revealed that girls had higher manual dexterity and balance skills than boys. And boys had higher than girls aiming and catching skills.

Conclusion The obtained result with the largest effect size allows us to assume that training in motor inhibition could probably help improve movement difficulties, especially in manual dexterity skills.

Clinical trial number Not applicable.

Keywords Preschool children, Executive function skills, Motor competence, Manual dexterity, Aiming and catching skills, Balance skills, Movement Assessment Battery for Children-2

Background

Preschool age is a period of active development of motor competence (MC) [1, 2]. MC describes proficiency in fundamental movement skills [3, 4]. MC plays a key role in human development [5]. MC contributes to children's language, cognitive, and social development [6–11]. High MC in childhood promotes engagement in physical activity and gives more chances for successful participation in a healthy lifestyle and sports throughout the lifespan [12]. MC is necessary for children to explore and interact with their environment [13]. MC is important for day-to-day play [14]. Preschoolers with MC difficulties more often spend time as onlookers during play compared to children without such difficulties [15]. Thus, low MC can interfere with exploring the environment and culture. Nowadays, the formation of high MC in preschoolers is threatened due to a sedentary lifestyle, which is associated with excessive screen time [16]. Not only physical activity affects MC, but also other not-so-well-explored predictors. One may be executive function skills because they are the foundation for a child's development [17]. Understanding MC predictors is important to develop evidence-based interventions to improve motor

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development in children, which is critical for quality of life.

MC in preschool children is assessed based on the success of mastering fundamental movement skills according to age norms [18]. Fundamental movement skills are goal-directed organized movement patterns [19, 20]. Normal development of fundamental movement skills allows one to handle motor tasks optimally, focusing on the result of the movement. Fundamental movement skills include locomotor skills (movements to transport the body from one point to another, e.g., running, leaping, galloping, etc.), manipulative or object control skills (movements to give an object force or get force from an object, e.g., aiming, catching, kicking, etc.), and balance skills (static balance – ability to maintain a desired still positions, e.g. when standing on one leg; dynamic balance – ability to control the body as it moves in space, e.g. when climbing or walking along the curb) [21]. At senior preschool age, MC already includes not only gross motor fundamental motor skills but also manual dexterity skills ("the ability to make coordinated hand and finger movements to grasp and manipulate objects") [22, 23]. According to Piaget and many other researchers, manual dexterity skills for preschool children are means of learning about the world is [13]. Fundamental motor skills as well as simple manual dexterity skills begin to establish at ages 2 to 7 [1, 23]. These skills (and therefore MC) are primarily acquired through play and imitation [21, 24]. Fundamental motor skills are the foundation for more complicated motor skills needed for play, leisure activities, physical activity, and sport [1].

MC in preschool children is affected by various factors [1]. A child's MC depends on individual genetic and biological factors, anthropometric characteristics, physical activity, physical fitness [12, 25–28]. The preschool environment (time in open spaces, structured activity experiences, and availability of outdoor playground space) is important for MC formation [29]. There is evidence that place of residence also affects MC: children living in the village tend to have higher MC as children living in the suburbs and downtown [30]. Children in low-income families, countries, and regions may disadvantage in MC development because of poorer health and other reasons [31]. There may be also culture differences in different countries affecting MC development, however, this topic has hardly been studied [31]. Age affects MC due to biological maturation [9, 32]. Another factor that potentially affects MC is sex. According to the most of the studies, preschool girls have higher proficiency in balance skills [1, 33–37] and manual dexterity skills [33–37] than preschool boys. Boys at 5–6 years are more proficient than girls in object control skills [34, 38, 39]. Regarding locomotor skills, several studies found that boys have better locomotor skills than girls [39], whereas another found the opposite [38]. However, several studies have found no sex differences in locomotor skills proficiency [40, 41], object control skills [42], balance skills [43]. Therefore, no conclusion has been reached on sex differences in preschoolers' MC [38]. Studies have shown that MC is also interrelated with executive function skills [9, 44–50].

Preschool age is a period of active and rapid development of MC and executive function skills (EF skills) [51, 52]. EF skills – "a set of general-purpose control processes that regulate one's thoughts and behaviors" [53]. The conceptualization of EF skills is a polemical topic. Some researchers divide EF skills into cold (cognitive) and hot (affective) [54, 55]. Baggetta and Alexander [56] proposed a distinction between domain-general and domain-specific EF skills. There are unitary and modular views of EF skills [52]. The unitary view postulates that there are high intercorrelations among various EF skills. Moreover, some factor analytic studies showed that EF skills are a single cognitive ability [52, 57]. On the contrary, the modular view postulates that EF skills are independent modules. In sum, there are different EF skills models in terms of EF skills number, nature, and degree of separation or unity [52, 58].

Most researchers concur that EF skills encompass various mental processes: inhibition, working memory, cognitive flexibility, attention, planning, self-monitoring, self-regulation, and initiation [53, 59]. The most known and cited EF skills model is the model by Miyake et al. [60] (unity-but-diversity model). Initially, this model was proposed for adults, but it has been proven to apply to preschool children [51, 61]. According to the model by Miyake et al. [60], there are three core EF skills: inhibition (the ability to suppress distractions that aren't relevant to the objective; inhibition is divided into cognitive and motor), working memory (the ability to hold and process information required for current cognitive tasks; working memory is divided into verbal and visual), and cognitive flexibility (the ability to shift and switch thoughts, behaviors, and emotions in response to environmental changes). Mental processes such as planning, reasoning, and problem-solving are built from these core EF skills [51, 52]. According to the unity-but-diversity model, EF skills are connected by hierarchical relationships. Working memory is the first in the hierarchy, followed by inhibition. Cognitive flexibility develops later, in the late preschool period [52]. The Miyake et al. [60] EF skills model was used as the theoretical framework of the current research.

EF skills development at preschool age predicts academic success, life achievement, health, and well-being in adulthood [62–68]. EF skills in the preschool period play a crucial role in ensuring development in general [17] and motor development in particular [69].

A small number of research have examined the association between EF skills and MC in preschoolers. Escolano-Pérez et al. [1] found in a study with 43 5–6-years-old Spanish children that children with higher working memory obtained higher scores on locomotor skills, and children with higher inhibition scores – had higher balance scores. Object control skills were not affected by the level of EF skills. This study measured only these two EF skills with a tool in which the EF skills of children are teacher-rated. In the research by Han et al. [2] with 394 children aged 3–5 years from Shanxi (China), fundamental motor skills were studied as EF skills predictors. It was shown that locomotor skills are significant predictors of working memory, inhibition, and cognitive flexibility, while object control skills are only significant predictors of inhibition. In a study by Oberer et al. [46], positive correlations were found between MC (gross motor skills and manual dexterity skills), and all evaluated EF skills (inhibition, switching, updating) in 156 6-year-old children from Switzerland. Cook et al. [48] found that inhibition was associated with locomotor and object control skills, whereas working memory was only associated with locomotor skills. There was no association between motor skills and cognitive flexibility. Only locomotor and object control skills were evaluated in this study to assess MC. One hundred twenty-nine children aged 3–6 years from urban and rural low-income settings in South Africa participated in this study. A cross-sectional study of the association between gross motor skills and EF skills in 25 normal-weight and 24 overweight 3–5-years-old children from Brazil was conducted by Fernandes et al. [70]. In overweight preschoolers, worse cognitive flexibility, working memory, planning, and problem-solving were associated with worse gross motor skills. In normal-weight children, there are no associations between EF skills and gross motor skills. Thus, most studies have shown an association between inhibition and MC, an association between working memory and MC is less common, and an association between cognitive flexibility and MC is found in isolated studies.

There are different explanations for the association between MC and EF skills. The first theoretical framework that explains how MC and EF skills are interrelated is reciprocity [71]. Reciprocity refers to the co-development of EF skills and MC through interaction with the environment [71, 72]. Learning motor skills support EF skills development, which supports motor development [71]. The second theoretical framework is automaticity [71]. Automaticity refers to the idea that complex skills mastering depends on more rudimentary skills [71]. It means that motor and cognitive processes compete for limited attentional resources when both motor and cognitive components are required [71, 72]. Automaticity of motor skills frees up attentional resources to perform cognitive tasks and vice versa. The third framework on the interrelation of MC and EF skills is from neuroscience. MC and EF skills have a shared underlying neuronal network: dorsolateral prefrontal cortex, cerebellum, and connecting structures [71, 73]. To sum up, the causal mechanisms of the association between MC and EF skills are bi-directional. However, the effects must still be fully understood [74].

Taking into account all the above, the association between MC components and EF skills has yet to be thoroughly studied in preschoolers [1, 5, 72]. Previous studies of this relationship have been conducted mainly on schoolchildren. The extent to which the results can be generalized to preschoolers is still unclear [9]. Furthermore, studies that involved preschoolers usually only included some EF skills and components of MC [9]. Studies usually selectively focused on one or two EF skills and separately locomotor, object control, balance, or manual dexterity skills [9]. The present study examined which EF skills may predict MC and its components in typically developing preschool children. The research questions were: (1) Are there any sex differences in MC? (2) Which EF skills are predictors of MC? (3) Which EF skills are predictors of each MC component?

Methods

Participants

Three hundred fourteen children without developmental disabilities were recruited to participate in the MC assessment. Still, three of them did not complete all the tasks because their caregivers took them home. Of the 311 children who passed the MC assessment, 272 participated in the EF skills assessment. Of the 311 children who passed the MC assessment, 39 were absent from kindergarten on the days of the EF skills assessment due to illness or other reasons. Therefore, the sample consisted of 272 typically developing preschool children (46% girls) aged 5 to 6 years. All children attended public kindergartens in Moscow. A questionnaire for caregivers showed that most of the children were from middle SES families: 98% of mothers had higher education, 77% of families had a medium income level. However, it is important to consider that family income in this study was estimated subjectively from parents' words. A comprehensive overview of the demographic variables is in Table 1.

Measurements

Movement Assessment Battery for Children-2 (M-ABC-2) [23] was used to assess MC. Age band 1 (from 3 years, 0 months to 6 years, 11 months) comprises eight tasks

Table 1 Demographic variables

Variables	Total sample, *n* = 272
Mean Age	70.5 ± 4.12 months
Sex	
Girls	46%
Boys	54%
Mother's education	
Primary school (9 years)	1 (0.5%)
High school (11 years)	2 (1%)
Bachelor's degree	34 (16.7%)
Master's degree	147 (72.4%)
PhD	19 (9.4%)
Not reported	69
Family income level	
Below average	1 (0.5%)
Average	155 (77.1%)
Above average	45 (22.4%)
Not reported	71

belonging to three components: three tasks checking manual dexterity skills, two tasks checking aiming and catching skills, and three tasks checking balance skills. Before each task, children receive verbal explanation and demonstration of the task performance. Moreover, after explanation and demonstration, children make a training trial until they understand the instructions clearly. In the first task checking manual dexterity skills, the child should put 12 plastic coins in the bank box as quickly as possible. In the second task, the child should lift the lace and thread 12 beads as quickly as possible. In both tasks, the result in seconds is recorded. In the third task, the child should draw a single continuous line from point A to point B, following the trail without crossing the boundaries. The number of errors is recorded. In the first task checking aiming and catching skills, the child should catch a 200-g beanbag thrown by the examiner with two hands. The examiner should stand on the special mat separated by 1.8 m from the child's mat. There are 10 hit attempts, and the number of successful attempts out of 10 is recorded. In the second task, the child should throw the beanbag 10 times, attempting to land it on any part of the target mat. Also, the number of successful attempts out of 10 is recorded. In the first task checking balance skills, the child should stand on one leg on the mat with freely held arms for up to 30 s. The standing foot must be fixed, and the free foot must be off the floor. The number of seconds, up to 30, the child maintains balance is recorded. In the second task, the child should walk with heels raised along the 4.5 m line on the floor without stepping off the line. The number of correct consecutive steps from the beginning of the line is recorded. In the last task, the child should make five consecutive continuous jumps from mat to mat, taking off and landing with the feet together each time. The number of correct consecutive jumps is recorded.

Regarding the test scoring, the row scores are converted to the standard scores for each of the 8 tasks. This conversion differs for children aged 5 years 0 months – 5 years 11 months and children aged 6 years 0 months – 6 years 11 months. The standard scores for three test components and MC components are determined: manual dexterity skills – maximum standard score 57; aiming and catching skills – maximum standard score 38; balance skills – maximum standard score 57; MC—maximum standard score 152.

The NEPSY-II 'Sentences Repetition' subtest [75] assessed verbal working memory. The child must remember one by one 17 sentences that progressively become more difficult, grow in length, and become more grammatically intricate. 2 points are given for each correctly repeated sentence, 1 point for a sentence with not more than 2 errors, and 0 points for more errors (maximum total score = 34).

The NEPSY-II subtest 'Memory for Designs' was used [75] to assess visual working memory. There are four trials (with 4, 6, 6, and 8 images) where the child must select the appropriate cards and place them on a grid in the same location as previously shown (maximum total score = 120).

The NEPSY-II subtest 'Inhibition' [75] assessed cognitive inhibition. The child must name forty figures (squares, circles, and arrows) that are the opposite of those actually pictured. Time devoted to each task and the number of errors (both corrected by a child and not corrected) are recorded. These parameters are converted into a combined scaled score (from 1 to 20 points) based on corresponding tables.

The NEPSY-II subtest 'Statue' [75] assessed motor inhibition. The child has to stay immobile for 75 s without being disturbed by a special sound stimulus (knocking, coughing, or the sound of a pen falling on the floor). The child gets 0 to 2 points for successfully following instructions for each 5-s period (maximum score = 30).

'Dimensional Change Card Sort' [76] assessed cognitive flexibility. There are 24 cards: 12 with rabbits and 12 with boats. On six cards, rabbits are blue, and on the other six cards, they are red (on a white background). The same goes for the cards with boats. Half of the cards have a black frame. The initial task is to separate 6 cards by color (put red cards on one side and blue ones on the other). The following task is to separate 6 cards by shape (boats and rabbits separately). The final task with 12 cards is to switch depending on the presence of the frame from sorting cards by color to sorting them by form. The child gains 1 point for each correctly sorted card (maximum total score = 24).

A questionnaire for caregivers was used to collect sociodemographic data about children and their family's socioeconomic status (SES). There were two questions about SES. The first question, "What is your family income?" had the following answer options: "below average," "average," "above average," and "other." The second question, "What is the education level of the mother of the child?" had the following answer options: "Primary school," "High school," "Bachelor's degree," "Master's degree," "PhD," and "Other." Also, there were two questions about sociodemographic data: the first about the child's date of birth and the second about the child's sex. Data on the family's SES were collected to describe the sample. Data on SES is important as children's EF skills are known to be related to it [77]. Data on a child's date of birth and sex were used in the analysis to examine sex differences and the role of age in MC.

The M-ABC-2 was used on a Russian sample for the first time, so UK norms were used [23]. All the NEPSY-II subtests used in the study and 'Dimensional Change Card Sort' tool have been translated and validated for the Russian population [78].

Procedure

The MC assessment was the first, and the EF skills assessment was conducted a week later. Both assessments were performed between 8 and 11 am. Specially trained examiners administered the assessment. All examiners successfully passed an exam, proving that they did all the assessment tasks correctly. Before the assessments, all caregivers provided written informed consent for their child's participation in the study. After the assessment, the children's caregivers received a questionnaire about sociodemographic data via email.

The MC assessment was conducted in the sports hall and took about 25–40 min with one child. It was administered individually, but there were simultaneously three examiners and three children in the sports hall. The first examiner administered tasks to one child, checking manual dexterity skills. Then, the second examiner administered the same child tasks, checking aiming and catching skills. Finally, the third examiner tasks checking balance skills. After one child completed the tasks checking manual dexterity skills and moved on to the second examiner, a new child came to the first examiner, and so forth. To avoid distracting each other, the children did tasks with their backs to each other and in different areas of the sports hall. The assistant brought the children to the sports hall individually and then, after assessment, took each child away. All children wore their usual sports clothing and shoes during the tests.

The assessment of EF skills was carried out individually for each childy. Eight examiners were preliminarily trained to perform this EF skills assessment. The EF skills assessment was carried out using a specially created application for tablets [79]. The process of instructing the child and recording his or her answers for each task was done automatically using the application. The examiner only turned on the application and monitored how the child performed the tasks. In the application, the tasks were run to all the children in the same order. This automation ensured the unification of assessment by all eight examiners. Also, the unification was ensured because all the examiners used the same tablet model (Samsung Galaxy tab 6). The EF skills assessment was divided into two 20-min sessions with three days of break between. The first session included verbal working memory and cognitive inhibition tasks. The second session included visual working memory, cognitive flexibility, and motor inhibition tasks. Children were tested in a quiet room in their kindergarten (in the bedroom or psychologist's office).

The Ethics Committee of the Faculty of Psychology at Lomonosov Moscow State approved this study and its consent procedures (approval No: 2023/18).

Data analysis strategy

Data analysis was carried out in the Jamovi 2.0.0.0 software. For all the tests the level of significance was set to $p = 0.05$. The normality of the distribution was examined with the Shapiro–Wilk test. Since the data were not normally distributed, nonparametric methods were used onwards. Descriptive statistics (Mean, Standard Deviation) and Spearman correlation were used for preliminary analysis to explore five EF tests measures, four MC indexes measures, and participants' age, and their associations. Strengths of the Spearman correlation (r_s) were interpreted as follows: $r_s = 0.1–0.39$ weak correlation, $r_s = 0.4–0.69$ moderate, and $r_s \geq 0.7$ strong [80]. A Mann–Whitney U test was performed to evaluate whether MC, EF skills, and age differed by sex. Sex differences in EF skills and age were examined to rule out the possibility that sex differences in MC were due to differences in EF skills and age. Rank biserial correlation (r_b) was used to calculate the effect size for the Mann–Whitney U test. Interpretation of rank biserial correlation was as follows: $r_b < 0.10$ represented a very small effect, $r_b = 0.10–0.29$ small effect, $r_b = 0.30–0.49$ moderate effect, and $r_b \geq 0.5$ large effect [81]. The general linear model was performed to test EF skills and participants' age as MC predictors. Three general linear models with significant MC predictors from the previous general linear model were performed to test EF skills and age as manual dexterity, aiming, catching skills, and balance skills predictors. Partial eta squared (η^2p) was used to calculate the effect size for the General Linear Model. Values of 0.01, 0.06, and 0.14 indicated small, medium, or large effects [82].

Results

Preliminary analysis: descriptive statistics and correlation analysis for EF skills and MC

Table 2 presents the descriptive statistics for the EF and MC skills measures. Shapiro–Wilk test indicated that all parameters except verbal working memory and aiming and catching skills were not distributed normally (see Table 2).

Table 2 Means, Standard Deviations and Shapiro–Wilk test for EF skills variables and MC variables

	M	SD	Shapiro–Wilk, W	Shapiro–Wilk, p
Verbal working memory	19.2	3.55	.986	.008
Visual working memory	71.0	19.9	.969	< .001
Cognitive inhibition	11.1	3.06	.983	.002
Motor inhibition	26.6	3.94	.775	< .001
Cognitive flexibility	20.4	3.02	.930	< .001
Manual dexterity skills	25.7	7.47	.938	.002
Aiming and catching skills	16.4	4.49	.985	.007
Balance skills	29.6	5.95	.937	< .001
Motor competence	71.7	13.7	.983	.003

Correlations between the included variables are shown in Table 3. There were weak positive correlations between all EF skills (except cognitive inhibition and motor inhibition with no correlation between them). There were weak positive correlations between MC components, and all MC components were strongly correlated with MC (except aiming and catching skills with moderate correlation). There were weak positive correlations between manual dexterity skills and visual working memory, motor inhibition, and cognitive flexibility. The same is true regarding balance skills and motor competence. In the case of aiming and catching skills, there were weak correlations only with visual working memory and motor inhibition. The age in months was significantly weakly correlated with all the included variables (except verbal working memory).

Sex differences in MC

Table 4 presents differences between boys and girls. Girls had a higher level of manual dexterity skills and balance skills than boys. Boys had a higher level of aiming and catching skills than girls. The effect size of these results was small. There were no sex differences in the EF skills and age.

Table 3 Spearman correlations among the EF skills variables, MC variables, and participants' age

		1	2	3	4	5	6	7	8	9
1. Verbal working memory	r_s	-								
	p	-								
2. Visual working memory	r_s	.194								
	p	.001								
3. Cognitive inhibition	r_s	.134	.293							
	p	.027	< .001							
4. Motor inhibition	r_s	.189	.158	.080						
	p	.002	.009	.186						
5. Cognitive flexibility	r_s	.359	.276	.212	.214					
	p	< .001	< .001	< .001	< .001					
6. Manual dexterity skills	r_s	.047	.282	.056	.326	.183				
	p	.444	< .001	.362	< .001	.002				
7. Aiming and catching skills	r_s	.038	.181	.036	.247	.041	.343			
	p	.532	.003	.553	< .001	.503	< .001			
8. Balance skills	r_s	.101	.174	.049	.258	.138	.372	.302		
	p	.095	.004	.420	< .001	.023	< .001	< .001		
9. Motor competence	r_s	.089	.287	.050	.365	.163	.830	.642	.722	
	p	.141	< .001	.414	< .001	.007	< .001	< .001	< .001	
10. Age	r_s	.047	.202	-.174	.185	.161	.286	.242	.213	.316
	p	.436	.001	.004	.002	.008	< .001	< .001	< .001	< .001

Table 4 Sex differences in the EF skills variables, MC variables, and participants' age

	Boys, *n* = 147		Girls, *n* = 125		U-Mann–Whitney test	p	Effect size, r_b
	M	SD	M	SD			
Verbal working memory	19.1	3.36	19.2	3.76	8911	.668	.030
Visual working memory	70.1	20.07	72.0	19.81	8644	.401	.059
Cognitive inhibition	11.0	3.20	11.2	2.89	8719	.466	.051
Motor inhibition	26.2	4.49	27.1	3.12	8396	.215	.086
Cognitive flexibility	20.1	3.20	20.7	2.78	8072	.082	.121
Manual dexterity skills	24.6	7.50	27.1	7.23	7264	.003	.209
Aiming and catching skills	17.1	4.62	15.6	4.19	7586	.013	.174
Balance skills	28.7	6.37	30.5	5.29	7763	.027	.155
Motor competence	70.4	14.30	73.2	12.79	8137	.104	.114
Age, months	70.5	4.01	70.5	4.26	9157	.962	.003

Table 5 General linear model based on the EF skills, participants' age, and sex as MC predictors

	SS	d	F	p	η^2p
Model	13,439.0	7	13.6127	< .001	.265
Verbal working memory	18.8	1	.1334	.715	.001
Visual working memory	992.0	1	7.0334	.008	.026[a]
Cognitive inhibition	161.4	1	1.1441	.286	.004
Motor inhibition	5063.5	1	35.9025	< .001	.120[b]
Cognitive flexibility	12.6	1	0.0890	.766	.000
Age	2836.6	1	20.1126	< .001	.071[b]
Sex	129.5	1	.9185	.339	.003
Residuals	37,233.2	264			
Total	50,672.2	271			

[a] small effect, [b] medium effect, large effects

EF skills as predictors of MC

The general linear model based on the EF skills and age as MC predictors was significant, but the effect size was small (Table 5). As age was significantly correlated with MC, age was also added to the model as a potential MC predictor. The result of this general linear model demonstrated that visual working memory (small effect size), motor inhibition (medium effect size), and age (medium effect size) are significant MC predictors (Table 5).

EF skills as predictors of each MC component

Significant MC predictors (visual working memory, motor inhibition, age) from the previous model were included in the four final models: a general linear model for MC and three separate models for each of the three MC components: manual dexterity skills, aiming and catching skills, and balance skills (Table 6).

In the general linear model for MC, motor inhibition and age had a medium effect size as MC predictors and visual working memory had a small effect size (Table 6). In the general linear model for manual dexterity skills, motor inhibition had a medium effect size as a manual dexterity skills predictor. In contrast, visual working memory and age had a small effect size (Table 6). In the general linear model for aiming and catching skills, motor inhibition, and age were predictors with a small effect size, and visual working memory was not a predictor (Table 6). All three predictors (visual working memory, motor inhibition, age) had a small effect size in the general linear model for balance skills (Table 6).

Discussion

Sex differences in MC

The first research question of the present study was about sex differences in MC.

In the present study, sex differences in MC were found: girls had higher levels of manual dexterity and balance skills, and boys had higher levels of aiming and catching skills. No sex differences in age and EF skills were found. Due to this, it can be argued that the sex differences in MC were not due to the sex differences in age or EF skills. These sex differences in MC can be attributed to how preschoolers usually spend their leisure time: boys play more with balls, while girls do activities such as drawing, rope skipping, and other balancing games [35, 83]. The same sex differences were revealed in the majority of the studies [33–37, 84]. However, in the study by Singh et al. [43], no differences in balance skills between preschool boys and girls were found [43]. In the study, children (30 boys and 19 girls) were aged 3–4 years. The possible reason for the absence of differences between boys and girls in balance skills in this study is the different ages of children. It can be assumed that at 5–6 years of age, the sex differences in balance skills become more pronounced at 3–4 years. Also, there were studies showed no sex differences in object control skills [42]. In the study by Bakhtiar

Table 6 General linear models for MC and its components are based on main MC predictors

		Visual working memory	Motor inhibition	Age	Model	Residuals	Total
Manual dexterity skills	SS	378	1792	555	3610	11,522	15,131
	df	1	1	1	3	268	271
	F	8.80	41.69	12.91	27.99		
	p	.003	< .001	< .001	< .001		
	η^2p	.032[a]	.135[b]	.046[a]	.239		
Aiming and catching skills	SS	51	106	291	597	4859	5456
	df	1	1	1	3	268	271
	F	2.81	5.84	16.07	10.98		
	p	.095	.016	< .001	< .001		
	η^2p	.010	.021[a]	.057[a]	.109		
Balance skills	SS	138	501	119	1006	8599	9605
	df	1	1	1	3	268	271
	F	4.29	15.62	3.71	10.46		
	p	.039	< .001	.055	< .001		
	η^2p	.016[a]	.055[a]	.014[a]	.105		
Motor competence	SS	1468	5626	2656	13,125	37,547	50,672
	df	1	1	1	3	268	271
	F	10.5	40.2	19.0	31.2		
	p	.001	< .001	< .001	< .001		
	η^2p	.038[a]	.130[b]	.066[b]	.259		

[a] small effect, [b]medium effect, large effect

[42], there were no significant sex differences for object control skills, but boys were slightly higher than girls in these skills. In this study, children were one year older (67 children 6–7-years old) than in the present study. Object control skills were evaluated with the following tasks: striking, stationary dribbling, catching, kicking, overhand throw, and underhand roll [42]. In the present study, object control skills were evaluated only with aiming and catching tasks. Due to the different number and complexity of the tasks, it is not entirely appropriate to compare the results obtained in the present study and the study by Bakhtiar [42]. Hence, a broader picture of the sex differences in MC of preschoolers is needed. It is important to note that two of three MC components (manual dexterity and balance skills) evaluated in M-ABC-2 are components in which girls tend to be superior [35]. In studies with the M-ABC-2 tool, preschool girls are more likely to get a higher score in tasks checking manual dexterity and balance skills, and boys in tasks checking to aim and to catch. Clinicians who use M-ABC-2 to identify children at risk of motor impairment should be aware that boys and girls do not perform M-ABC-2 in a similar way.

EF skills as predictors of MC

The second research question was to determine which EF skills were MC predictors. This research revealed that MC was predicted by visual working memory, motor inhibition, and age. Motor inhibition as an MC predictor had the largest effect size. This outcome is consistent with the results and ideas of other researchers [5, 9, 47, 85]. This result is related to the fact that there is a congruence between MC and motor inhibition: both require inhibitory control and body movements [47]. In the M-ABC-2 test, the MC score is the sum of the scores for three components. Therefore, to discuss EF skills as MC predictors, it makes sense to consider each MC component in more detail.

EF skills as predictors of each MC component

The third research question was to determine which EF skills were predictors of each MC component: manual dexterity skills, aiming and catching skills, and balance skills.

EF skills as MC components predictors: EF skills as manual dexterity skills predictors

Manual dexterity skills were predicted by visual working memory, motor inhibition, and age. The effect size of motor inhibition as a manual dexterity skills predictor was the largest. The nature of the M-ABC-2 tasks checking manual dexterity skills might explain this. First, only these tasks were required to perform as quickly as possible. Unnecessary movements lengthen the time it takes to complete the task. This means that all movement features play a role in performing tasks checking manual dexterity skills. Second, in the tasks checking manual dexterity skills, the finest control of movement execution is required. It is in these tasks that the result and efficiency are more dependent on the accuracy of movement execution and movement trajectory. Some imprecision is acceptable in the tasks checking aiming and catching skills, and balance skills. In these tasks only achieving the movement goal matters. For example, when catching the beanbag or standing on one leg, the child can make free body movements if they do not disrupt the instruction or interfere with the outcome. However, in the tasks checking manual dexterity skills, hand movements must be very precise. Third, manual dexterity skills in preschool are not yet automated; therefore, they require more significant involvement in more EF skills, especially motor inhibition [2, 9, 72]. The finding of the study that visual working memory was a predictor of manual dexterity skills is consistent with previous studies [5, 9, 50, 85, 86]. The connection between visual working memory and manual dexterity skills can be explained by the tasks checking manual dexterity skills requiring an accurate visual perception of the stimuli and their location. In addition, successful task performance means that visual and motor information must be integrated [72]. For example, to quickly and accurately put coins into a slot, the child needs to keep the exact location of the coins and all their characteristics in working memory to adjust the movement of the hand to these parameters. It is the same as for other tasks checking manual dexterity skills.

EF skills as predictors of each MC component: EF skills as aiming and catching skills predictors

Aiming and catching skills were predicted by motor inhibition and age. Age had the largest effect size, but this effect was small. This result can be explained by normal maturation processes and similar developmental timelines for EF skills and motor development during preschool [9]. Visual working memory was a predictor for the other two MC components but not for aiming and catching skills. Visual working memory is less involved in the two M-ABC-2 tasks checking aiming and catching skills. It can be assumed that it is because, in these tasks, it is not necessary to keep small visual details and their mutual location in the visual working memory. Moreover, tasks checking aiming and catching skills are the most similar to the exercises that children do in sports classes with a ball. This means that these movements are more familiar and automated than the movements required for other M-ABC-2 tasks. Also, only in tasks checking aiming and catching skills does an examiner participate in movements with a child when they throw a beanbag to the child 10 times (catching task). In all other tasks, an examiner only watches the child's movements. It can be assumed that such an examiner's involvement implies that the child needs to use his working memory less than in the other tasks. If more object control skills were assessed (not only aiming and catching) in the study, the EF skills would play a more important role as predictors.

EF skills as predictors of each MC component: EF skills as balance skills predictors

Balance skills were predicted by visual working memory, motor inhibition, and age. Motor inhibition had the largest effect size, but all three predictors had a small effect. Other studies have also shown that motor inhibition [5, 9, 47, 85] and visual working memory were predictors of balance skills [5, 9, 50, 85, 86]. In one of the M-ABC-2 tasks checking balance skills, motor inhibition is especially required when standing on one leg for up to 30 s with the standing foot fixed and the free foot off the floor. This task was difficult for most of the children in the study sample. The connection between visual working memory and balance skills can be explained by the fact that one M-ABC-2 task checking balance skills (walking heels raised) requires an accurate visual perception of the line taped to the floor and the location of the feet. It is important to note that static and dynamic balance were not analyzed separately in the current study. In the M-ABC-2 tool, the general balance skills standard score (which is the sum of scores from the three tasks checking balance skills) was used. And the same goes for manual dexterity and balance skills.

EF skills which were not predictors of MC

The present study revealed that cognitive inhibition, verbal working memory, and cognitive flexibility were not predictors of MC and its components. Furthermore, no correlations existed between these EF skills, MC, and its components. The absence of these associations was shown in other studies [5, 47, 48, 85, 87, 88]. The examiner stays nearby while the child completes all the M-ABC-2 tasks, carefully observes the completion, and does some tasks with the child. Therefore, the child does not need to actively use cognitive inhibition when doing M-ABC-2 tasks. The absence of a significant association between verbal working memory and MC, as well as cognitive flexibility and MC, may be related to the M-ABC-2 assessment procedure: all the instructions are explained to the child verbally and through demonstration. The task begins only after the child understands the instructions clearly and after the training trial. Therefore, verbal working memory and cognitive flexibility are challenged. The connection between cognitive flexibility and MC was shown only in one reviewed study [9]. The study's authors supposed that their result could be explained by the nature of motor tasks in their research [9]. They used the Bruininks-Oseretsky Test of Motor Proficiency, second edition (BOT-2) [89]. The test tasks were less familiar to the children; therefore, they had to rapidly change their attention between simultaneous goals for successful task performance [9]. Here are tasks from BOT-2: touching nose with index fingers eyes closed; pivoting thumbs and index fingers; walking forward on a line; one-legged side hopping; push-ups, and fine motor tasks (coloring a star; drawing a line through a path; stringing blocks; copying overlapping circles; copying a diamond; catching a ball with one hand; dribbling a ball using alternate hands) [9]. Compared to M-ABC-2 used in the present study, these tasks are less like everyday play and exercise. It can be assumed that M-ABC-2 performance does not place high demands on cognitive flexibility. Additionally, it can be suggested that cognitive flexibility was not a predictor of MC when using the M-ABC-2 because cognitive flexibility was comparatively poorly developed compared to other EF skills in preschool age. Cognitive flexibility develops at an older age after working memory and inhibition [48, 52].

Limitations and strengths of the study

The present study has limitations. First, the current study did not show causality of the association between MC and EF skills, nor showed a possible reciprocal association between MC and EF skills. Thus, longitudinal research is required. Second, most of the effect sizes of the results in the study were small. Small effect sizes point to limited practical applications of the results. Third, there was no data about individual genetic, biological, and sociological elements that affect MC (e.g., level of physical activity, physical fitness, participation in sports or dance classes, etc.) [5]. Almost all the children were from middle or high-SES families. However, the results may differ in children from low-SES families [48]. Fourth, M-ABC-2 tool was not validated for the Russian population. So, standard scores equivalents of raw scores on each test item were calculated according to UK norms [23]. However, there might be cultural differences in motor performance [34, 48, 90], so standard scores equivalent to raw scores for the Russian sample are needed in the future. Fifth, there are no separate norms for boys and girls in M-ABC-2, while motor skills do not develop similarly in boys and girls at this age.

One of the strengths of the current study was that the tool 'Movement Assessment Battery for Children-2' was used on the Russian sample for the first time. Obtaining data on M-ABC-2 for children from different countries is scientifically valuable because there are shown to be cross-cultural differences in MC [30, 31, 34, 48, 90]. Furthermore, the number of boys and girls was nearly the same, therefore equally representing both sexes. Finally, the tools used to assess EF skills were validated for the Russian population and recognized as valid and reliable.

Conclusions

This cross-sectional design study examined whether EF skills predict MC in preschool children. Results indicated that higher visual working memory, motor inhibition, and age were predictors of higher MC. Visual working memory, motor inhibition, and age-predicted manual dexterity and balance skills. Aiming and catching skills were predicted by motor inhibition and age. The outcome was that motor inhibition was manual dexterity, and the MC predictor had the greatest practical value. Because this result had the largest effect size – medium close to large. This outcome could imply that training in motor inhibition could help improve deficits in MC, especially in manual dexterity skills. Future studies would benefit from longitudinal design. Likewise, assessing data about different factors that can affect MC would be prudent. Also, the authors suggest that future studies validate M-ABC-2 on Russian samples and develop separate norms for boys and girls.

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Authors' contributions
Conceptualization, MG; methodology, EC, MG; writing-original draft preparation, EC; writing-review and editing MG and PD; All authors have read and agreed to the published version of the manuscript.

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Data availability
The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
All procedures performed in the study involving human participants were in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. This study and its consent procedures were approved by the Ethics Committee of Faculty of Psychology at Lomonosov Moscow State University (the approval No: 2023/18). All caregivers provided written informed consent for their child's participation in the study.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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