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Assessment of motor skills associations with executive functioning in children of senior preschool age

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Abstract

Context and relevance. The article examines the relationship between motor skills (fine and gross motor skills, motor reaction time) and executive functioning (EF), which is the most important predictor of future academic success. **Objective.** This experimental study is designed to determine the strength and direction of associations between EF components (planning ability, working memory, inhibitory control) and various motor skills (gross and fine motor skills) in older preschool children. **Hypothesis.** In preschool children, EF components (planning ability, working memory, inhibitory control) have close associations with various indicators of motor development, but so far, this has not been unambiguously confirmed in experimental studies. **Methods and materials.** The examination of the participants was conducted within the framework of the project “Study of neurobiological predictors of academic success in children” (Priority 2030) using the hardware and software system SHUHFRIED (Tower of London — Freiburg version, TOL-F; Motor Learning Skills test, short form according to Sturm and Büssing, MLS; Reaction Time test, RT; n = 81, 58 boys, average age 6.42 ± 0.53 years) and the stabilometric complex ST-150 (65 children, 52 boys, average age 6.4 ± 0.52 years). **Results.** According to the correlation analysis of the stabilometry and TOL-F test indices, the lower the gross motor skills (postural stability) indices, the better the planning and working memory indices; however, the inhibitory control index directly correlates with postural stability skills. The results of the fine motor skills and EF tests mostly agree with each other; however, they have lateralization characteristics, and the size of the correlation coefficients does not exceed 0.4. **Conclusions.** The correlations of the fine motor skills test results with EF are mostly weak. Probably, at the preschool education stage, the impact only on the motor sphere (fine motor skills in particular) is not a sufficient condition for the development of EF. Planning and working memory inversely correlate with the gross motor skills development indices, which probably indicates a reciprocal relationship between individual higher cortical functions and gross motor skills in older preschool age.

Keywords: executive functioning, postural stability, fine motor skills, gross motor skills, motor response

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Оценка ассоциаций двигательных навыков с показателями исполнительного функционирования у детей старшего дошкольного возраста

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Резюме

Контекст и актуальность. Материалы статьи посвящены проблеме взаимосвязи двигательных навыков (мелкая и крупная моторика, время моторной реакции) с исполнительным функционированием (ИФ), которое является важнейшим предиктором дальнейшей академической успешности.

Цель данного экспериментального исследования — определить силу и направленность ассоциаций компонентов ИФ (способности к планированию, рабочей памяти, тормозного контроля) с различными моторными навыками (крупной и мелкой моторикой) у детей старшего дошкольного возраста. **Гипотеза.** Предполагалось, что у детей дошкольного возраста компоненты ИФ (способность к планированию, рабочая память, тормозный контроль) имеют тесные ассоциации с различными показателями двигательного развития, т.к. до сих пор это не имеет однозначного подтверждения в экспериментальных исследованиях. **Методы и материалы.** Обследование участников проводилось в рамках проекта «Исследование нейробиологических предикторов академической успешности детей» (Приоритет 2030) с помощью аппаратно-программной системы SHUHFRIED (методика Башня

Лондона, Фрейбургская версия, англ. Tower of London — Freiburg version, TOL-F; тест Навыки моторного обучения, краткая форма по Штурму и Бюссингу, англ. Motor Learning Skills, MLS; тест Времени реакции, англ. Reaction Time, RT; $n = 81$, 58 мальчиков, средний возраст — $6,42 \pm 0,53$ лет) и стабиллометрического комплекса ST-150 (65 детей, 52 мальчика, средний возраст — $6,4 \pm 0,52$ лет). **Результаты.** Согласно корреляционному анализу показателей стабиллометрии и теста TOL-F, чем ниже показатели крупной моторики (постуральной устойчивости), тем лучше показатели планирования и рабочей памяти, однако показатель тормозного контроля прямо коррелирует с навыками постуральной устойчивости. Результаты тестов на мелкую моторику и ИФ преимущественно согласуются между собой, однако имеют особенности латерализации и размер коэффициентов корреляции не превышает 0,4. **Выводы.** Корреляции результатов тестов на мелкую моторику с ИФ являются преимущественно слабыми. Вероятно, на этапе дошкольного образования воздействие только на двигательную сферу (мелкую моторику, в частности) не является достаточным условием для развития показателей ИФ. Планирование и рабочая память обратно коррелируют с показателями развития крупной моторики, что, вероятно, говорит о реципрокном взаимоотношении отдельных высших корковых функций с крупными моторными навыками в старшем дошкольном возрасте.

Ключевые слова: исполнительное функционирование, постуральная устойчивость, мелкая моторика, крупная моторика, моторная реакция

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Introduction

According to research, the most significant cognitive predictors in preschoolers are executive functions (EF) [3; 23; 41]. EF is a general term for cognitive processes that regulate, control, and manage other cognitive processes [2; 6]. The content of EF construct

is variable, but most authors highlight working memory, attention (switching and distribution), cognitive flexibility, inhibitory control, planning, error search and correction, and problem-solving behavior [2; 14].

Deficits in EF development predict subsequent academic deficits in elementary

school: problems with literacy, reading, vocabulary, and mathematics [3; 34; 41; 44]. The predictive power of the EF is maintained when controlling for other factors [23; 33]. Longitudinal studies have shown that EF development helps accelerate the rate of mathematical skills development [25; 40; 44]. Thus, the level of EF development can act as a fundamental predictor of academic success [22].

Other studies have shown a positive correlation between math performance and motor skills (MSs)—fine motor coordination and visual-motor integration [24]. J. Piaget argued that cognitive and motor processes cannot be considered as separate entities, since cognitive development is entirely dependent on motor functioning [37]. According to the Russian neuropsychology school, higher mental functions are functional systems that unite several areas of the brain to implement a particular function [1]. In childhood, the development of MSs is far ahead of the formation of speech and thinking, forming the basis for their formation, in connection with which corrective work should be directed from moving to thinking [5]. P.S. Churchland proposed the existence of a continuum of motor and cognitive functions [15].

There is little experimental evidence to support a *global* association between cognition and MSs. In a meta-analysis, Gandotra et al. (2021) showed significant positive associations of MSs with EF in neurotypical children (32 studies, N=4866), but the effect size of the *global* association of MSs and EF was very small: $r=0,18$ [26]. According to a systematic review by Malambo et al. (2022) on the relationship between EF and various MSs in preschoolers, the authors found only 15 studies on the topic, of which only half were of high methodological quality [32]. The authors found *weak* correlations or *insuffi-*

cient evidence for an association between the studied MSs and EF. According to Cameron et al. (2012), EF and fine MSs make *independent* contributions to the development of preschoolers' academic skills [12]. Thus, to date, the literature data on the relationship between MSs and EF in older preschoolers remain contradictory. Older preschool age is critically important for preparing a child for school, since it immediately precedes the start of education. Understanding the extent to which MSs and EF indicators are associated with each other at this age, and what the details of these relationships are, is relevant from the point of view of choosing the most effective strategies for preparing children for school.

Hypothesis: In preschool children, components of EF (planning ability, working memory, inhibitory control) may have close associations with various indicators of motor development.

Objective of this study was to analyze the associations of EF components (planning ability, working memory, inhibitory control) with various MSs (gross and fine motor skills) in older preschool children.

Methods and materials

The children were examined as part of the project “The Study of Neurobiological Predictors of Academic Success in Children.” Inclusion criteria: written voluntary consent of the parent; child's age of inclusion: 5 years 10 months–7 years 4 months; child's ability to understand and follow instructions. Exclusion criteria: previously diagnosed hearing, vision, and motor disorders; severe mental and neurological disorders diagnosed by a psychiatrist and/or neurologist; concussion within the last year, other traumatic brain injury or neurosurgical intervention; paroxysmal activity on the EEG; alalia (motor, sensory); severe

chronic diseases, malformations, cachexia, hereditary diseases; chronic mental disorders, alcohol and/or drug addiction in parents.

The MSs assessment was carried out using the hardware and software complex (HSC) SHUHFRIED (81 children, 58 boys, average age $6,42 \pm 0,53$ years, here and further the arithmetic mean $\pm$ standard deviation) and the stabilometric complex ST-150 (65 children, 52 boys, average age $6,4 \pm 0,52$ years); the assessment of the EF was carried out using the HSC SHUHFRIED (81 children, 58 boys, average age $6,42 \pm 0,53$ years).

Stabilometry is one of the basic methods of posturology, which studies the processes of maintaining, controlling, and regulating body balance in its various positions and performing movements [8]. Testing the process of body balance in the basic stance (Romberg test) provides information on the functional state of the musculoskeletal system [8]. Body balance (postural stability) is one of the basic components of gross MSs [39]. As part of this work, a test was performed to assess the stability of the vertical posture — the Romberg test.

Three subtests were analyzed using the HSC SCHUHFRIED (Vienna Test System, Austria):

1. The Tower of London test, Freiburg version (TOL-F). The main variables assessed are planning ability (the ability to cognitively model alternative solutions and evaluate the consequences of an action before it is performed) [9], working memory, and inhibitory control [43] (EF). The validity of the TOL-F was confirmed in the study by Debelak et al. (2016) [18].

2. The MLS test (short form, according to Sturm and Bussing) includes 8 subtests (4 in each hand) and evaluates fine MSs: purposefulness of movements, calmness of the hands/tremor, precision of hand and wrist

movements, dexterity of hands and fingers, and speed of hand and wrist movements, speed of wrist and finger movements.

3. RT (reaction test) is used to assess reaction time and motor reaction time.

To date, data on the experience of using the HSC SCHUHFRIED in Russia for conducting psychological and pedagogical research have been published [7; 9].

Data analysis was performed using the StatSoft Statistica 6,0 package. The data distribution was different from normal (Shapiro-Wilk test), and Spearman's rank correlation coefficient (hereinafter ρ) was used to assess correlations between variables. Correlations were considered significant at a level of $p < 0,05$.

Results

1. The assessment of correlations between the indicators of postural stability and EF is presented in Table 1.

From the analysis of Table 1, it can be noted:

1). The larger the area of the statokinesio-gram (S), the better the planning ability and the more correctly 4-move tasks are solved (reflects working memory); however, at the same time, the choice of an unacceptable position (an indicator of inhibitory control) occurs more often. S is an indicator of postural stability: the larger S, the worse the balance skills.

2). The higher the statokinesio-gram density (LFS, path length per unit area), the lower the planning ability and the fewer correctly solved tasks, but at the same time there are fewer errors (choosing an inadmissible position). LFS reflects energy expenditure when maintaining a posture; the higher it is, the less energy is expended, which means that balance skills are better developed and auto-

Table 1

Correlation matrix (Spearman) of stabilometric indicators with indicators of executive functioning

Stabilometry indicators	Planning ability	Correctly solved tasks		Invalid position selection	Number of correct decisions
		4 moves	5 moves		
V OE	0,065	0,174	–0,026	0,049	–0,205
V CE	0,059	0,043	0,023	0,119	–0,251*
S OE	0,250*	0,267*	0,216	0,267*	–0,065
S CE	0,201	0,181	0,152	0,279*	–0,110
LFS OE	–0,299*	–0,286*	–0,277*	–0,295*	–0,010
LFS CE	–0,223	–0,147	–0,242	–0,378**	0,021

Note: * — $p < 0,05$; ** — $p < 0,01$; V — the speed of the pressure center movement is the ratio of the length of the trajectory of the center of pressure to a unit of time; the higher the value of this indicator, the less stable is the person's posture on the platform (Skvorcov, 2010); S — statokinesiogram area; LFS — statokinesiogram density; OE — open eyes; CE — closed eyes (tests with open and closed eyes allow one to assess the contribution of the visual and proprioceptive sensory systems to maintaining balance).

mated [8]. Thus, the more effective the postural balance strategy, the lower the planning and working memory indicators, but at the same time there are fewer errors with choosing an inadmissible position (better inhibitory control). LFS is inversely correlated with S; therefore, the correlations of these indicators with EF have the opposite sign.

Thus, according to the analysis of correlations between gross MSs indicators and TOL-F test indicators, the less stable the child is and the more energy he spends on maintaining his posture (the less developed his balance skills), the better he performs on planning and working memory tests but has more erroneous attempts (the less developed his inhibitory control).

2. The analysis of correlations of the EF indicators with the results of fine MSs testing (MLS test) is presented in Table 2.

From the analysis of Table 2, it can be noted:

1). Planning ability negatively correlates with the error number and duration of the MLS aiming test (visual motor coordination

assessment) with the right hand and is also positively correlated with the number of hits with the right hand.

2). The number of correctly solved TOL-F tasks inversely correlates with the duration of the left-hand hit in the aiming test and with the duration of the left-hand error in the hand stability test and directly correlates with the number of left-hand errors in the stability test. In other words, a greater number of errors with their shorter duration in the stability test and a shorter duration of the hit when aiming, only with the left but not the right hand, corresponds to a greater number of correct solutions in the TOL-F test. In addition, the number of correct TOL-F solutions directly correlates with the number of hits in the tapping test with both hands.

3). The choice of an invalid position in the TOL-F is positively correlated with the number of right-hand aiming errors and negatively correlated with the total duration of the hitting and tracing tasks. That is, the stability and accuracy of task performance in the fine MSs test (MLS) are positively correlated with the inhibitory control score (TOL-F).

Table 2

**Correlation matrix (Spearman) of the results of the Tower of London and MLS
(Fine Motor Skills Test)**

Fine motor skills test scores (MLS)		Planning ability	Invalid position selection	Number of correct decisions
Hit (targeting)	Number of errors, L.	–0,120	0,182	–0,106
	Number of errors, R.	–0,301**	0,255*	–0,174
	Error duration, L., sec	–0,106	0,140	–0,123
	Error duration, R., sec	–0,280*	0,163	–0,199
	Total duration, L., sec	0,160	–0,340**	–0,263*
	Total duration, R., sec	0,102	–0,382***	–0,126
	Number of hits, L.	0,080	–0,129	–0,059
	Number of hits, R.	0,339**	–0,034	0,142
Tracing lines	Total duration, L., sec	–0,013	–0,284*	0,120
	Total duration, R., sec	0,134	–0,239*	–0,014
Hand stability	Number of errors, L.	0,002	–0,041	0,377***
	Error duration, L., sec	–0,065	0,174	–0,303**
	Number of errors, R.	0,034	0,053	0,192
	Error duration, R., sec	–0,010	0,206	–0,207
Tapping	Number of hits, L.	0,068	0,114	0,242*
	Number of hits, R.	0,136	–0,041	0,324**

Note: L. — left hand, R. — right hand; * — $p < 0,05$; ** — $p < 0,01$; *** — $p < 0,001$.

3. The correlations of EF with the reaction test (RT) indices are presented in Table 3.

From the analysis of Table 3, it can be noted:

1). The choice of an unacceptable position in TOL-F (indicator of inhibitory control) directly correlates with the time of completing RT tasks—the slower the child reacts in RT,

the more often he makes mistakes in choosing a position in TOL-F.

2). The number of correct decisions in TOL-F inversely correlates with the number of missed and incomplete reactions RT and directly correlates with the number of correct reactions RT.

Thus, the results of testing the EF are completely consistent with the results of the

Table 3

Correlation matrix (Spearman) of the results of the TOL-F (Tower of London) test and the RT (reaction time) test

Reaction time (RT) test scores	Planning ability	Invalid position selection	Number of correct decisions
Processing time	–0,064	0,287*	–0,081
Reaction speed	–0,103	0,268*	–0,206
Number of missed reactions	–0,018	0,184	–0,352**
Number of correct reactions	0,080	–0,206	0,367**
Number of incomplete reactions	–0,116	0,145	–0,278*

Note: * — $p < 0,05$; ** — $p < 0,01$.

RT test: the faster and more accurately the child completes RT, the more correct decisions and fewer mistakes in TOL-F he makes.

Discussion

According to the obtained data, MSs have a *weak* connection with the results of EF testing using TOL-F. All significant correlations do not exceed the absolute value of 0,4, and only a few indicators have a moderate correlation (0,3–0,4). This is not consistent with Piaget's thesis that cognitive development is *entirely* dependent on motor functioning [37], but rather indicates a *weak* association of MSs with EF in older preschool children. Our data are consistent with the results of the meta-analysis by Gandotra et al. [26], in which the authors also obtained data on a *very weak* effect size of the EF association with various MSs. Considering the weak correlations, and even negative ones for some MSs, we can agree with the conclusions of Cameron et al. (2012) [12] about the relative independence of EF from MSs. Probably, each of these areas requires *separate* attention when preparing a child for school, and only motor development (including fine MSs) is not enough for optimal preparation.

A detailed analysis of the obtained results shows that gross MSs have a weak negative correlation with planning and working memory indicators. The worse a child's balance skills are, the better his EF indicators are. This contradicts some studies on the close relationship between basic MSs and academic performance [30], especially in the field of mathematics [18]. However, the authors of the first study [30] assess academic performance as a whole, without singling out mathematics separately, while the authors of the latest study [18] emphasize that performance on *dynamic* motor tests has a greater impact on mathematical performance. The study by

Cook et al. (2019) showed that individual gross MSs and components of EF have different and even opposite associations: inhibitory control is associated with locomotor skills and object manipulation skills. Working memory is associated only with locomotor skills, and physical activity did not correlate with inhibition and switching attention and was inversely correlated with working memory [17]. Ludyga et al. (2019) did not find any associations between cognitive flexibility and MSs in a study of preadolescent children [31]. Thus, our data and the results of other authors indicate that different components of EF have different degrees and directions of associations with individual indicators of gross MSs.

Inhibitory control as measured by the TOL-F is positively correlated with balance skills, which complements the findings of Cook et al. (2019) on the association of inhibition with locomotor skills and manipulation [17]. Our findings are also consistent with the findings of Liu et al. (2022) on the association of gross MSs with inhibitory control in preschoolers [29]. Liu et al. (2022) suggested that this is due to overlapping neural networks in the brain regions responsible for these functions [29].

In modern psychology of cognitive development, there are two theoretical concepts about the relationship between MSs and cognitive skills: reciprocity (development of motor and cognitive skills in close interaction) and automatism (struggle between MSs and cognitive skills for attention) [26]. To perform and improve new MSs, more cognitive resources (attention) are required. However, strengthening of skills leads to automation and reduction of cognitive resource expenditure on their performance. Our data are more consistent with the second concept.

In a large study of the association of cognitive and motor functions in 5–6-year-

old children ($n=378$), no relationship was found between global aspects of cognitive and motor functions [42]. Some positive relationships were identified between visual-motor integration and working memory and between quantitative aspects of motor activity and verbal fluency. A study of 5th graders showed that postural stability was associated with linguistic academic achievement but not with mathematical achievement [38]. Another study demonstrated that of all motor functions (gross and fine MSs), only fine MSs (namely, visual-motor coordination) predicted subsequent mathematical achievement ($n=38$, 5-6 years) [21]. Our results are consistent with these data and suggest that individual EF may develop relatively independently of the development of gross MSs.

In the fine motor skills test (MLS), only the right-hand scores correlate with planning ability, and in the hand stability test (MLS), a higher number of errors with the left, but not the right, hand directly correlates with the number of correct solutions in TOL-F. This may indicate the role of lateralization of hand functions and a greater association of fine MSs of the right hand with EF, which is consistent with the data of the meta-analysis by Gandotra et al. (2021) [25].

The findings of a positive correlation between fine MSs and motor speed tests and EF are consistent with a large body of previously reported data on this topic: performance

on fine motor tests is a predictor of division problem solving [16]; visual-motor coordination in preschool age is a significant predictor of mathematical skills [13; 20; 24; 26]. Most researchers note that it is visual-motor coordination that is the key skill that determines future academic performance in mathematics. According to Nesbitt et al. (2019) [35], improvement in mathematical abilities over time correlates with the development of EF and visual-motor integration.

Conclusion

Correlations of fine MSs with EF are weak; therefore, at the preschool stage, the development of the motor sphere alone is probably not sufficient to develop EF indicators. Only inhibitory control directly correlates with gross MSs; planning and working memory have inverse correlations with postural stability, which probably indicates a reciprocal relationship between individual EF (planning) and gross MSs in older preschool age. Thus, the assertion about the global relationship between MSs and EF is not supported by the results of the experimental study. Further detailed studies of the relationship between individual gross and fine MSs with different components of executive functioning are required to optimize the child's preparation for school.

Limitations. The cross-sectional nature of the study does not allow us to speak about the causality of the revealed correlations.

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Тарадай Ю.М. — участие в сборе данных, формировании базы данных, участие в написании раздела «Обсуждение результатов».

Борисова А.М. — участие в сборе данных, написании разделов «Введение», «Обсуждение результатов».

Все авторы приняли участие в обсуждении результатов и согласовали окончательный текст рукописи.

Conflict of Interest

The authors declare no conflict of interest.

Конфликт интересов

Авторы заявляют об отсутствии конфликта интересов.

Ethics Statement

The study was reviewed and approved by the Ethics Committee of Privolzhsky Research Medical University (report no 7, 2024/17/05).

Декларация об этике

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