Original Article

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The relationship of cognitive abilities and motor proficiency in preschool children – pilot study

Lenka Vojtíková [1ABCD], **Jan Hnízdil** [2ACD], **Ivana Turčová** [1BDE], **Wojciech Statowski** [3,4D]

[1] Charles University, Prague, Czech Republic
[2] Department of Physical Education and Sport, Faculty of Education, Jan Evangelista Purkyně University in Ústí nad Labem, Czech Republic
[3] Department of Kinesiology and Health Prevention, Jan Dlugosz University of Czestochowa, Poland
[4] Department of Medical and Molecular Biology, Faculty of Medical Sciences in Zabrze, Medical University of Silesia, Katowice, Poland

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Abstract

Introduction: This study aimed to evaluate the relationship between cognitive abilities and motor skills in a selected group of preschool children. *Material and methods*: We measured 56 children (27 girls, 29 boys; average age 5.97±0.42). The level of motor proficiency was measured using the short version of the BOT-2 test, and cognitive abilities were measured using the colored trail making test for children. *Results*: Girls scored better on all test items, and the observed differences were not statistically significant, except for the difference in fine manual control. For this category, the results for girls were significantly better than those for boys (p<0.01). The effect size of the observed differences in cognitive and motor skill levels between girls and boys had a large effect. The results showed a strong correlation between the level of cognitive abilities and the level of motor profieciency in preschool children (r=0.61; p<0.01) in the whole group as well as when assessing correlations separately for the group of boys (r=0.64; p<0.01) and the group of girls (r=0.50; p<0.01). Moderate to moderately strong correlations have been proved between the level of cognitive ability and the level of motor profieciency in particial motor categories: manual coordination (r=0.65; p<0.01), fine manual control (r=0.52; p<0.01), and body coordination (r=0.50; p<0.01). The relationship between the level of cognitive ability, strength, and agility was weak (r=0.34; p<0.05). Considering all test limits, the process of testing, and preschool age specifics, we can state that there is a strong correlation between motor and cognitive abilities. *Conclusions*: Motor and cognitive ability development are closely related. The results of this study demonstrated the importance of complex development and early screening. The results of this study can serve as another useful insight related to previous claims in the field of the development of cognitive abilities and motor proficiency.

Keywords: cognitive abilities, preschool children, motor development

Corresponding author: Lenka Vojtíková, email: vojtikova.lenka@seznam.cz

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INTRODUCTION

From practical experience and defined children needs [1-4] we know that exercise is a means of learning about the living environment, first learning how to manage one's own body, cope with one's surroundings, express oneself, and communicate with one's surroundings. Locomotion is a basic need of a preschool child, enabling the practical realization of many life competences, and it is an important means of discovering the world and therefore an integral part of all learning. Most learning in preschool children is realized through games that contain movement. Learning through movement and exercise is a comprehensive interconnection of learning processes, and for children, it is a very efficient way of gaining new skills and knowledge [5-8]. Movement activities present far more than muscle engagement, as the simple act of play engages the entire neural system. This creates subconscious recations such as processing stimuli and information, problem-solving and decision making, and synchronized and processed alongside intentional motor reactions [6,9,10]. Early childhood is the most critical and intensive period in brain development. This period is characterized by the dynamic overproduction of synapses, first in the area of sense perception and later in the areas included in the process at the higher level. These areas, such as working memory, attention, planning [11-13] and physical activity, can have a positive influence on cognitive development [14,15]. In general, research in this area aims to identify relationships and causality among the levels of motor proficiency, cognitive abilities, and school success. The concrete values of the observed relationships differ, which can be caused by different methodological approaches or the concrete aims of individual studies.

Many international studies observing the relationship between cognitive abilities and motor development have confirmed through their results a mutually positive relationship between these two components in preschool children [9,16-22] etc. Several studies [12,23,24] do not prove a relationship between cognitive abilities and motor development at the global or general level; however, they mention the existence of specific relationships and connections between different components of motor skills and different components of cognitive abilities, meaning that different motor skills require specific abilities for performance.

The level of motor proficiency during the preschool period can predict the level of motor development and cognitive abilities in later years [19,25,26]. Bushnell and Boudreau [13] state that low motor fitness at an early age predicts possible later problems with the level of many cognitive abilities. For example, the development of attention and memory is necessary to cope with the demands connected to the entry level of primary school. Bornstein et al. [10] confirmed that children who manage their motor skills more profeceintly have higher cognitive functions at the age of four.

Children with special educational needs or behaviors and learning difficulties had a worse score in motor skills. More able children have both components above average, which proves the relationship between motor skills and brain development, more precisely, cognitive abilities [25,27,28].

When determining factors influencing school success, the relationship between academic success and level of motor development has been proven. Proper motor development has an impact on cognitive skill development, which is also evident in the success of further education [10,18,29,30]. Cadoret et al. [31] proved that the level of motor proficiency is related to academic success, but that the influence is indirect through cognitive abilities. Primarily, motor proficiency influences cognitive abilities, which is reflected in more recent studies. Children with difficulties in motor areas (e.g., coordination disorder) have worse study results compared to children who reach standard motor levels [27,30]. By including and supporting motor activities in the educational process, we can positively influence the level of motor proficiency, cognitive abilities, and learned knowledge, both in children with standard development and in children with different disabilities or learning difficulties [14-16,18,31-33]. These studies emphasize the basic meaning of motor skills for school study results in children in their early school years.

According to Kucera [33], preschool children naturally move five to six hours a day if they are not constrained. Movement improves orientation in a body scheme, orientation in space, balance, coordination, soft motor skills, and the ability to concentrate [34], which are attributes that prevent learning disorders. Disrespecting the need for movement is one of the reasons for learning and behavioral problems [6]. The preschool period is essential for the early detection of disabilities and is where possible quality intervention can take place. We hypothesized that there would be a relationship between the level of cognitive abilities and the level of motor skills in a selected group of preschool children. Therefore, our aim was to evaluate the relationship between these indicators.

MATERIAL AND METHODS

Participants

The research was conducted with three selected classes in two nursery schools (one in Prague and one in the central Czech region). Fifty-six children participated in the study (27 girls and 29 boys) with an average age of 5.97±0.42 years. This person was granted and approved by both nursery schools and the two parents before the study took place. Parents were informed of the research processes, methods, and realizations. None of the children had any mental or physical restrictions or disabilities. Participation in the study was voluntary and cost-free. Before testing, children were asked whether they wanted to participate in the activity. Children could stop testing at any point and could choose not to complete the study; however, this did not occur in any case.

The ethical aspects of the study were followed during the research. We observed the children's reactions and answered questions related to the research. Children were identified under numbers so that we could guarantee their anonymity. We did not set any further conditions for this study. Relating to the demanding data collection, character of testing, and specifics related to the children's age (children's cooperation required at least a minimum of trust in the administrator), we decided to choose the children we had already cooperated with. Therefore, the sample was casual and non-random.

Procedure

Motor proficiency

To measure motor proficiency, we used the short version of the Bruininks-Ozeretsky Test of Motor Proficiency Ed. 2 (BOT-2 SF) [35]: The test primarily serves to identify children with different motor disproportions and disrupted motor development, but it can also be used for general evaluation of the level of motor proficiency in the common population. BOT-2 is also recommended for screening studies, development and evaluation of motor training programs, and for supporting other research studies. The age range for using this test is 4–21 years, and the BOT-2 test (and its possible modifications) can reliably identify children with significant motor problems and, at the same time, can serve as a basic motor test in healthy children [36,37]. The short version contained 14 tasks, which were selected such that each subcategory was represented in at least one task. The subcategories and tests are as follows:1. Fine Manual Control FMC (fine motor precision: drawing lines through paths, folding paper; fine motor integration: copying a square, copying a star); 2. Manual Coordination MC (manual dexterity: transferring pennies; upper-limb coordination: dropping and catching a ball, dribbling a ball); 3. Body Coordination BC (bilateral coordination: jumping in place, tapping feet and fingers; balance: walking forward on a line, standing on one leg on a balance beam); 4. Strength and Agility SA (running speed and agility: one-legged stationary hop; strength: knee push-ups, sit-ups). The performance of the tested children was measured using a rough score, which was later transferred to a standard point score according to age based on USA normative data [35]. According to the point summary, we set the overall score of the Total Motor Composite (TMC), which shows that the overall motor abilities of an individual and children were classified as significantly over-average (>70), over-average (60-69), average (41-59), under-average (31-40) and significantly under-average (<30).

Cognitive ability (CA)

This test is based on the original Trail Making Test, which is frequently used to evaluate attention and other cognitive functions. The authors Snoblova and Krejcova [38] adapted it in such a way that preschool children who do not know the alphabet or numbers are not limited in fulfilling this test. The test was standardized for the Czech Republic. The test is conducted for children aged 5 to 7 years, and it can be used as part of school maturity diagnostics. Next, we observe a child's visual space orientation. Results Children reached in the colored trail making test for children correlated with results reached in sub-tests focused on attention evaluation or planning selected diagnostic batteries, Woodcock-Johnson Tests of Cognitive Abilities, IDS, and CAS II. A low score in the test cannot be interpreted with the actual norms and should only serve as a recommendation for more complex attention diagnostics [38]. The test was created by 7 following tests of a progressive character. The task is to connect individual circles, which relate to color, and later to a shape with the same color. The difficulty increased from five points in the first and second tasks to 25 points in the last task.

Children were motivated to work as quickly as possible during the test. The administrator measured and recorded the time required to solve individual tasks. Next to the measured time, we counted the number of mistakes made by the children during the task. The time is decisive for the final result. Other remarks can serve as more complex diagnostics, based on this test. Results from the colored trail making test for children were based on a rough score (summary of measured times needed to solve individual tasks).

Data collection was always conducted in each class for four consecutive days during the morning educational time. On two of the days, we tested motor skills, and on the remaining two days, we tested cognitive abilities. All the tests were performed by the authors of this study. Teachers only helped with the organization and looked after children who were not tested. Realizing the motor test (BOT-2 SF) with one child lasted approximately 20-25 minutes. Testing cognitive abilities (including explanation and preparation) lasted approximately 10-15 minutes for one child.

Statistical Analysis

To express the correlation between cognitive ability and motor proficiency (including individual parts), we used the Spearman correlation coefficient. The correlation strength was evaluated according to Evans [40], who has set for the absolute value of the correlation coefficient r marking the mutual relationship as "very weak" 0.00 – 0.19, „weak" 0.20 – 0.39, „moderate " 0.40 – 0.59, „strong" 0.60 – 0.79, „very strong" 0.80 – 1.00. The t-test and Mann-Whitney U-test were used to determine the significance of the differences between the observed variables between the groups of girls and boys. Statistical significance was pre-determined at $p < 0.05$. As the research sample was not randomly chosen, we also considered the effect size – coefficient of determination (r^2) for correlation, Cohen's d for the t-test, and coefficient r for the Mann-Whitney U test [41]. The data were analyzed using Jamovi 2.3.18 solid software [42].

RESULTS

We recorded the basic characteristics of all tested children. Their ages, weights, heights, and BMI are presented in Table 1. To assess the significance of the differences between the groups of girls and boys, t-tests were performed. The observed difference in age and basic anthropometric variables between girls and boys was statistically insignificant, with a small effect size (d<0.2).

The means, standard deviations, and ranges for variables measuring cognitive ability and motor proficiency are presented in Table 2. All tasks in the Colored Trail Making Test for Children were accomplished by children in an average of 361.69 seconds, (i.e. approximately 6 min); the average time for boys was 399.02 sec, and the average time for girls was 324.34 sec. The mean BOT-2 SF standard score of observed group was 46.5 ± 13.2 points (42.5 ± 11.3 for boys, 52.0 ± 9.3 for girls).

Table 1. Basic characteristic of the sample (mean ± SD).

Indicator	group		Statistic	Total
	boys	girls		
age [years]	5.86 ± 0.46	6.07 ± 0.36	t=0.28; p=0.81; MD=0.21; d=0.05	5.97±0.42
weight [kg]	21.49 ± 3.98	20.66 ± 3.75	t=0.66; p=0.85; MD=0.83; d=0.13	21.05 ± 3.95
Height [cm]	117.73 ± 6.32	116.55 ± 5.78	t=0.82; p=0.62; MD=1.18; d=0.11	117.14 ± 5.98
BMI	15.02 ± 2.4	16.15 ± 2.02	t=0.32; p=0.38; MD=-1.13; d=0.18	15.32 ± 2.24

t: t-test, p: statistical significance, MD: mean difference, BMI: body mass index, d: effect size, Cohen's d

Table 2 Results from the tests of cognitive abilities and individual motor tests.

Test	group	Mean	Median	SD	Range
Cognitive Abilities (CA)	boys	399.02	381	280.68	805
	girls	324.34	312	125.39	498
	all	361.69	333.5	176.19	833
Fine Manual Control (FMC)	boys	14.4	16.5	5.32	19
	girls	18.64	19	3.42	12
	all	17.14	18	5.11	22
Manual Coordination (MC)	boys	6.5	6	3.44	11
	girls	8.09	8	2.39	10
	all	8.29	8	7.24	11
Body Coordination (BC)	boys	12.95	15	3.94	12
	girls	14.09	15	1.57	4
	all	13.36	15	3.01	12
Strength and Agility (SA)	boys	8.15	8	3.76	12
	girls	10.14	10.5	4.17	12
	all	8.67	8.5	4.23	16
Total Motor Composite (TMC)	boys	42.5	45.5	11.3	52
	girls	52	52.5	9.34	30
	all	46.5	48.5	13.2	59

SD - standard deviation

Table 3. Significance of differences between groups of girls and boys in cognitive ability and motor proficiency (Mann-Whitney U).

Test	U	p	MD	ES
Cognitive Abilities (CA)	123.00	0.07	74.68	0.60
Fine Manual Control (FMC)	76.00	< 0.001	-4.24	0.81
Manual Coordination (MC)	160.50	0.14	-1.59	0.52
Body Coordination (BC)	190.50	0.38	-1.14	0.44
Strength and Agility (SA)	141.00	0.10	-1.99	0.55
Total Motor Composite (TMC)	110.00	0.09	-9.50	0.62

U: Mann-Whitney test; p: statistical significance; ES: effect size; MD: mean difference.

Table 4. Categories according to the BOT-2 SF results.

Categories	Boys [n]	Girls [n]	Total [n]
significantly above-average (>70)	0	2	2
above-average (60-69)	4	5	9
average (41-59)	18	14	32
under-average (31-40)	5	5	10
significantly under-average (<30)	2	1	3

n – number

We found significant differences in the monitored variables between girls and boys (Table 3). The group of girls achieved better results in all area items; in CA, the girls had, on average, a lower time, in motor competence assessment, the group of girls had, on average, a higher score. In terms of statistical significance (p-value), these differences were not statistically significant. The difference was statistically significant only for fine motor (FMC) (p<0.001). In terms of effect size, the differences found were medium effect r <0.44-0.62>. The difference in the FMC had a strong effect (r=0.81).

Most children (according to the point gains) were included within the category "average performance" (Table 4). The results in the individual sub-categories were used to evaluate the relationship between individual motor areas and cognitive abilities.

Table 5. Correlation matrix for whole group.

Test	Gender	Cognitive Abilities (CA)	
		r	r^2
Fine Manual Control (FMC)	Boys	-0.533**	0.284
	Girls	-0.444*	0.197
	Total	-0.518*	0.270
Manual Coordination (MC)	Boys	-0.612*	0.375
	Girls	-0.572**	0.327
	Total	-0.645*	0.420
Body Coordination (BC)	Boys	-0.533*	0.284
	Girls	-0.442**	0.195
	Total	-0.504*	0.250
Strength and Agility (SA)	Boys	-0.261*	0.068
	Girls	0.106**	0.011
	Total	-0.339**	0.120
Total Motor Composite (TMC)	Boys	-0.636*	0.404
	Girls	-0.502*	0.252
	Total	-0.613*	0.370

*p<0.01, **p<0.05; r – Spearman's rho; r^2 - coefficient of determination

We evaluated the relationship between performance on the cognitive ability test and motor tests for the whole group (Table 5). A significant relationship was found between the overall motor proficiency expressed by TMC and CA (r=0.61; p<0.001). The level of the measured relationship is strong in this zone. The coefficient of determination (r^2) was 0.38. All observed sub-categories were related to the level of cognitive ability, and the measured relationships were statistically significant. The closest relationship was found between CA and MC; the level of correlation was in the zone of strong correlation (r=0.65), the measured relationship was significant (p<0.001), and the determination coefficient representing effect size was 0.42. The relationship between the CA and SA test results was evaluated as weak (r=0.34, p=0.028) with a low effect size, represented by the determination coefficient r^2=0.12.

When assessing the relationships of monitored variables, especially for a group of boys and girls (Table 5), the results did not differ from the relationships found for the whole group. A significant relationship was found between overall motor proficiency, expressed by TMC, and CA (boys: rs=0.64, p<0.001, r^2=0.40; girls: r =0.50, p<0.001, r^2=0.25). All observed subcategories assessed separately for a group of girls and a group of boys were related to the level of cognitive abilities, and the measured relationships were statistically significant. The strongest relationship was found between CA and MC (boys: r=0.61, p=0.004, r^2=0.38; girls: r=0.57, p=0.014, r^2=0.33). The relationships between CA and SA test results, as well as the result of the whole group evaluation, were evaluated as weak (boys: r=0.23, p=0.001, r^2=0.07; girls: rs=0.12, p=0.04, r^2=0.001).

DISCUSSION

After reviewing several studies [13,19,21,31], we presumed the existence of positive relationships between the level of motor proficiency and cognitive abilities in preschool children. Based on the evaluation of the test results of our pilot study, we confirmed the existing relationship between the level of cognitive abilities and the level of motor proficiency in the observed group of preschool children (r=0.61). The relationship between the level of cognitive ability and motor proficiency was also confirmed when the results were assessed separately for girls and boys. Based on the obtained values of coefficients of determination, we can conclude that the level of motor is from 25-40% influenced by the level of cognitive abilities and vice versa.

We also confirmed the relationship between CA and the subcategories of motor. All measured relationships were statistically significant. The closest relationship was found between the test results of the CA and MC. The weakest relationship was found between cognitive abilities and the sub-category Strength and Agility, level of motor is only from 1-7% influenced by the level of strength and agility. Tests in this category focused mainly on movement abilities, and two out of three tests measured strength. The results show a weaker relationship of abilities, which are, to a great extent, given, in contrast to skills, mainly manipulation, in which quality is influenced by motor experience influenced by opportunities and conditions. This is due to the influence of a family, sports club, or activities realized in nursery schools [5,6,43]. With respect to the rather small research sample, we cannot generalize our results; nevertheless, they show a trend, which has been proven in other studies.

In preschool children, gender differences in motor skills are usually not as noticeable [31,45]; they usually occur later in school age [17]. Certain differences are observed in the area of balance and fine motor skills, where girls dominate [44,45], and in the area of manual coordination (control of aids), where boys usually dominate [44,46,47]. In our study group, girls achieved better results in all tested variables (in terms of statistical significance, the differences were not significant; however, when assessing the effect size of the difference, it was assessed as moderate to strong. So we are only partly in agreement with the research, in the area of MC we would expect boys to achieve better results according to the research results. The reason for the observed discrepancy could also be that three children from the test group (girls) played tennis every week, so they were more successful than others in tasks in which they had to manipulate a tennis ball, even though they were average in other tests. Manipulation with a tennis ball is a specific skill, and previous experience will definitely influence the results. The BOT-2 SF test also does not include skill testing that requires the control of objects by the lower limb, in which boys usually dominate. This may also be the reason for the discrepancy with research results confirming the dominance of boys in manipulation skills [44,46,47].

Based on motor test results and cognitive ability test results, three of the tested children were sent to an expert, who later diagnosed deviations from normal development and recommended suitable support and intervention. All three children had significantly lower average scores. Two of these children were boys, which, given the small size of the group, may also have had an effect on the average results for the group of boys.

Our results are consistent with those of other studies [9,17-19,21,22]. However, a deeper comparison of the results at the international level is difficult because of the diversity of methods used in individual countries (especially in cognitive skills), different data collection methods, and research aims.

Many studies in this area have focused on school children. This can be caused by the accessibility of tests for preschool-aged children. Studies are partly limited by the individual development of preschool children (the difference between biological and calendar age), which is difficult to objectively determine, but does influence the results. Preschool children are also a specific group from the perspective of organization. It is necessary to count with more time and limits to understanding the instructions. It is necessary to build a relationship with the test administrator; children must trust the test administrator to cooperate. It is necessary to choose a specific form of instruction, including adequate motivation [6,8].

When testing strength, it is necessary to consider the willingness of preschool children to participate. Their performance is limited not only by their abilities but also by motivation. Including selected test items for testing strength (push-ups and sit-lies) can be controversial in children. When performing push-ups, they often perform them incorrectly (bending in the lumbar area). After correction, some children carried on in the right way, others returned to the wrong procedure, and therefore, we could not count their push-ups. It is difficult to determine whether the wrong procedure was caused by strength limits or incorrect habits. The exercise "sit-lie" is generally not recommended (work of supplemental muscles, doing the exercise by flip, etc.). The results of the motor testing were influenced by the individual experiences of the children.

Many tests are very difficult to use owing to financial and organizational constraints. In general, there are fewer tests for preschool children, there are often no norms for this age group, and there are often no norms in the Czech Republic. We chose the test battery BOT-2 SF to testing motor proficiency. The test is suitable with regard to its wide spectrum; even the short version can provide a complex and fairly precise picture of the level of motor proficiency of the tested children. We chose this test because of its high reliability and ease of realization and analysis. A disadvantage in lowering the study evidence is the absence of norms for the Czech population. We used the original test standardized for the Anglo-American area, which is the norm for the USA.

The colored trail making test for children is a simple and easily realized test, which we consider a suitable method for simple screening. The children were greatly interested in testing, and after finishing the test, they requested other similar tasks. This could have been caused by the joy of individual care and the interest in each child. We considered the test choice for this study to be suitable with respect to the conditions and study characteristics. More importantly, basic screening instruments evaluating aspects of normal development were accessible for common pedagogical work. This means that they can be used by teachers. Thanks to screening, it is possible to uncover deviations in children's development early, and this can be followed by recommending a more detailed consultation or examination for possible interventions [14,29].

Teachers in nursery schools and parents often perceive the need for the goal-directed development in the area of intellectual development. This is due to their perception of the correlation with academic achievement. Movement and exercise, whether spontaneous or directed, is often considered exclusively physical, developing only motor abilities and skills, or simply perceived as a form of relaxation and recreation. In general, motor activity is considered less "serious". The aim of creating sufficient time and quiet space for "more serious learning" restricts opportunities for children to practice motor skills, which can subsequently lead to less effective learning [6,15]. Nevertheless, the results of many studies prove that motor activity is related to the level of motor proficiency [29], which means that motor activity indirectly influences the development of cognitive abilities through improving motor proficiency [31].

This study aimed to support the significance of exercise in cognitive development. It is important that physical activity is not exclusively understood as the only means of ensuring academic achievement. It is necessary to understand and emphasize the meaning of physical activity for healthy development in the social, mental, and physical areas, including the prevention of diseases in civilization. It should be obvious that nursery schools should include physical activities, health exercises, and whole exercise units. The time devoted to exercising, its content, and its forms differ among schools.

In addition to organized physical activity, it is necessary to motivate preschool children to engage in spontaneous physical activity and to create adequate conditions and a stimulating environment for these activities. Simultaneously, it is essential to consider the structure of the day. Activities should be suitably changed and planned, but at the same time, we should react naturally to the actual state and needs of the child, so that their levels of physical movement are met and fulfilled for their age group [6,8,43]. Children at an early age create a relationship to physical activity through play, which develops, adapts, and extends into their further developmental years. Family plays an irreplaceable role in this lifelong attitude towards physical activities. Families who lead their children to physical activities and motivate them to move in the early years will create children with the habit of wanting to participate in physical activity as a part of their everyday lives as they grow. This is the first step toward health and balanced development [2].

We agree with the conclusions of other studies [14,15,17] that further research must be conducted to support and specify the current results. Studies could be aimed at intervention (what type of activity and how often). Research tests should be improved, standardized to certain conditions and ages, and suitable tests should be established not only for research but also for pedagogical work in terrain.

CONCLUSION

Our study suggests that, during the preschool period, motor skills were positively related to cognitive development ($p \leq 0.05$) in both girls and boys. This finding supports the thesis that early intervention by educators in the youngest age groups would lead to greater effectiveness. It is recommended that the development and promotion of motor skills be treated as an integral part of early childhood development programs to enable children to achieve optimal development and progress, both academically and physically.

Therefore, attention should be paid to the standardization of motor tests to ensure equitable consistency across the entire population of preschool children. Support from preschoolers to be included in the developmental screening program would also help identify national trends as well as assist in further producing a wider range of statistical results. Further and thorough study of this area and the widest possible discussion of the results at scientific forums and conferences is needed.

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