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The correlation between motor proficiency and working memory of Thai school-aged children

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ABSTRACT

Background: Motor proficiency encompasses both gross and fine motor skills while cognitive abilities include language, attention, memory, and executive functions that are gradually being developed in a period of life span during childhood. Currently, there is only indirect evidence linking motor proficiency and specific working memory performance.

Objectives: Purpose of this study was to determine the correlation between motor proficiency and working memory in Thai school-age children grades 1-4.

Materials and methods: One hundred and fifteen children were randomly recruited from a primary school in the Bangkok metropolitan area. Bruininks-Osteretsky Test of Motor Proficiency 2 Short Form (BOT-2 SF) was performed to test motor proficiency. The specific working memory ability was assessed by digit span forward and backward, and visuomotor construction.

Results: There was a significant correlation between motor proficiency and working memory in Thai school-age children grades 1-4 (r=0.51, p<0.001).

Conclusion: The current study indicated that motor proficiency and working memory were significantly correlated. Therefore, the link between school-aged children's motor proficiency and working memory may provide clarity regarding the connection of these abilities in children to guide curriculum development or appropriate interventions in a school setting.

Introduction

During the development of children, they learn many motor abilities which are defined as the skills that are integrated to efficiently coordinate the actions in a particular task.[1] The definition of the total motor proficiency generally involves gross motor skills such as jumping, sprinting, and walking by the underlying physical abilities using strength of muscle power, balance, flexibility, speed and agility. Moreover, fine motor skills refer to fine motor precision and integration. In the part of bilateral body coordination, it includes the whole body engagement with bilateral coordination of both arms and legs to perform activities.[2] Cognitive skills mean the mental processes or performances of obtaining knowledge and understanding through the senses, thinking and experience.[1] Executive functions are considered as the higher order cognition which are the broader terms of cognitive processes that engage in goal-directed activities.[3] One of the essential aspect of executive functions is working memory[4] which is necessary for processing of thinking, reasoning, decision-making, and desired behavior. It is the ability to store and manipulate data in short-term memory, by which particular processes exist using verbal and visual information.[5] Working memory has been found to constantly develop across life span of childhood to adolescence.[6, 7]

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It is well documented in literature that there is a strong relationship between motor and cognitive development.[8-10] This relationship is partly ascribed to the changes in brain function and structure that take place due to physical and motor training.[11] Motor skills are strongly important to the development of brain and has a positive influence on the ability to learn whenever cognitive skills are applied.[12] Currently, several evidences show that some specific working memory is more relevant to gross motor tasks, but this point remains controversial. Cross-sectional studies in adolescents have indicated that gross motor skills are related to visuospatial working memory.[13] There are contradictory studies that have reported on the relationship of gross motor skills with verbal working memory in 10 year-old children.[13, 14] The different aspects of gross motor skills were also shown to be related in different ways to working memory; it was found that locomotor skills were related to working memory in adolescents.[15]

In the research about the implementing programs aiming to improve motor skills have also been shown the benefits to enhance working memory. It has been found that a 10-week motor program increased working memory in 9–10-year-old children.[16] A soccer program also demonstrated in beneficial effects on motor skills and specific aspects of working memory.[17] This program enhanced visuospatial working memory, but there was no effect on verbal working memory. However, one current study found that a physical activity intervention for six months improved motor skills (manual dexterity, ball skills, and balance), but again there was no effect on working memory.[18] Recently, a cross-sectional survey of Dutch children from grades 3 and 4 also showed gross motor skills were significantly related to verbal working memory, visuospatial working memory, and response inhibition.[19]

School-aged children spend a majority of their time in school; an environment that influences their overall physical and learning development.[20] From the results of nationwide study showed that two thirds of Thai children and youth were not sufficiently active. Thai children and youth engaged in a large number of physical activities but the prevalence estimate of meeting the physical activity recommendations was low.[21] As gross motor proficiency is assumed to foster academic abilities,[22] evidence obtained from developmental movement programs which have been implemented in early childhood curriculum could enhance academic skills in reading and math.[23] The above-mentioned studies suggest that a curriculum which focuses on a child's physical activity to enhance motor proficiency may benefit neurodevelopment related to specific executive functions such as working memory that can result in the ameliorate of academic achievement. With increasing supportive evidence regarding the link between school-aged children's motor proficiency and working memory, there is more clarity about the key factors contributing to the connection of these abilities in children that will enable educational professionals to plan curriculum or classroom activities in schools. Furthermore, there is no currently supporting evidence regarding specific relations between gross motor skills and working memory. Thus, it seems necessary to conduct further research concerning the benefits of motor skills and proficiency. Therefore, the aim of this present study was to investigate the relationships between motor proficiency and working memory of school-aged children.

Materials and methods

Participants

One hundred fifteen children (63 boys and 52 girls) grade 1- 4 participated in this study were recruited from 4 primary school in the Bangkok metropolitan area, Thailand with the school selected opportunistically. Inclusion criteria were able to communicate and understand Thai language and have not been diagnosed for any neurological diseases such as cerebral palsy, movement disorders, or vision and hearing deficits. Then, children were randomly recruited. Informed consent was gained from parents of the child participants after they had read an explanatory statement and research information according to ethical principles. This study was granted ethics approval from Mahidol University Central Institutional Review Board (COA No. MU-CIRB 2018/136.2307).

Materials

For the motor proficiency test, the Bruininks-Oseretsky Test of Motor Proficiency 2 short form (BOT-2 SF) for children aged 4 to 21 was used to assess all participants in this study using the standardized version that shows high reliability for motor efficiency assessment.[2] Short form is less time-consuming (15-20 min per person) compared to the complete form (CF) (45-60min per person). The developers of the BOT-2 also demonstrated that the strong correlation between SF and CF existed r=0.80 to 0.87.[24] Therefore, BOT-2 SF can be used as a tool in this study. BOT-2 SF are clustered as 15 items of four motor area composite scores including fine manual control, manual coordination, body coordination, and strength and agility. Fine manual control tasks include drawing lines (crooked), folding paper, copying a star, and copying a square. Manual coordination tasks include transferring of pennies, dropping and catching a ball (with both and each hand) and dribbling a ball (with alternating hands). Body coordination tasks include tapping feet and fingers (with same body side synchronized), jumping in place (with same body side synchronized), standing on one leg (on beam) and walking forward on a line. Strength and agility tasks include sit-ups, push-ups (with knees or full legs), stationary hopping, and jumping in place.

Based on the Baddeley's model, the most common categorizations are auditory and visual (sometimes used verbal and non-verbal, respectively) working memory assessments that used in schools and clinical settings. Therefore, the assessments should target each of the two modalities auditory and visual.[25]

This study also assessed working memory using digit span (auditory working memory) and visuomotor construction (visual working memory). The digit span forward and backward tests were designed by Martin Turner and Jacky Ridsdale and were later revised in 2004.[26] Digit forwards testing was done using the following cue: "Listen carefully as I say some numbers. When I finish, you say them." Digits were given at the rate of one per second without any variation in pitch of voice throughout the test. The test was continued until the subject fails to repeat after the assessor on both trial pairs, then the scoring involves determining the total number of items correctly repeated forwards. For the Digit backwards the student was given the following directions: "Repeat these numbers after me, but this time I want you to say them backwards." Two practice samples of two digits were given initially. The child was reminded that the digits were to be reversed. Delivery and scoring were similar to digit forwards. Next, the standard score was calculated from the raw score. For visual working memory, the child was instructed to do the visuomotor construction using all 4 pieces of plastic shapes (one circle, one square, and two triangular shapes) to reproduce a 2-D model after examiner has displayed the model. The picture booklet which showed the 2-D model was placed on the dominant side of the child and the plastic shapes were placed on the other side. The 2-D picture was showed for 15 seconds and then the booklet was closed to allow the child to build the 2-D shape from memory within 180 seconds. Time used for construction was then measured.

Procedure

Firstly, the relevant demographic data were gathered such as age, gender, classroom grade, as well as the dominant hand, arm, and leg. Secondly, the motor proficiency test was performed and working memory tests was conducted using digit span forward and backward tests combined with the visuomotor construction, respectively. These tests were completed in a single session that took approximately 25-30 minutes to perform in a quiet room.

Statistical Analysis

BOT-2 SF, digit span forward and backward standard score and visuomotor construction time used raw scores were analyzed using descriptive statistics. Pearson correlation analysis was conducted on the relevant working memory and the overall motor proficiency value. Correlation coefficient criteria were considered as the following; r=0.90 - 1.00 as very high correlation, 0.70 -0.90 as high correlation, 0.50 - 0.70 as moderate correlation, 0.30 - 0.50 as low correlation, and 0.00 – 0.30 as negligible correlation. The statistics were performed using SPSS software (version 18.0) and the significance level was set at 0.05.

Results

Demographic data

The mean age of the boys was 8.75 years and the mean age of the girls was 8.85 years. The children were further divided into 4 different age groups. Grade 1 group consisted of 44 children (25 boys with mean age=6.8, SD=0.3 and 19 girls with mean age=7.2, SD 0.4). Grade 2 group was 29 children (11 boys with mean age=8.3, SD 0.3 and 18 girls with mean age=8.4, SD 0.3). Grade 3 group was 22 children (13 boys with mean age=9.4, SD = 0.3 and 9 girls with mean age 9.3, SD 0.2). The last group was grade 4 consisting of 20 children (14 boys with mean age=10.5, SD=0.2 and 6 girls with mean age=10.5, SD 0.3). The data also showed 107 children with right hand dominant, 8 children with left hand dominant, 107 children with right arm dominant, 8 children with left arm dominant, 106 children with right leg dominant, but 9 children with left leg dominant. Demographic characteristics of participants were presented in Table 1.

Table 1 Demographic characteristics of school-aged children.

Variable	
School-aged children	n = 115
Age	**mean±SD**
Boy	8.75±1.58
Girl	8.85±1.40
Age of each grade level	
Grade 1	
Boy	6.8±0.3
Girl	7.2±0.4
Grade 2	
Boy	8.3±0.3
Girl	8.4±0.3
Grade 3	
Boy	9.4±0.3
Girl	9.3±0.2
Grade 4	
Boy	10.5±0.2
Girl	10.5±0.3
Dominant hand	**n (%)**
Right	107±93.04
Left	8±6.96
Dominant Arm	
Right	10±93.04
Left	8±6.96
Dominant Leg	
Boy	106±92.17
Girl	9±7.83

Motor proficiency

Table 2 demonstrates the mean and standard deviations for the variables of the study. The results are shown in each subtest of BOT-2 SF and total motor score which are separated for boys and girls in the 4 grade groups. The results presented that grade 4 boys had the maximum total motor proficiency score; 73.29 (8.52) whereas grade 1 girls had the minimal total motor proficiency score; 65.32 (10.35).

Table 2 Mean±SD of standard score in each subtest of BOT-2 SF among the various grades.

Subtests of BOT-2 SF	Grade 1		Grade 2		Grade 3		Grade 4	
	Boys Mean±SD	Girls Mean±SD	Boys Mean±SD	Girls Mean±SD	Boys Mean±SD	Girls Mean±SD	Boys Mean±SD	Girls Mean±SD
Fine motor precision	12.76±1.45	13.00±1.53	12.55±1.57	13.00±1.59	13.46±0.97	13.33±1.00	13.43±1.16	13.33±1.63
Fine motor integration	8.52±0.71	8.37±1.38	8.18±1.47	8.50±2.07	9.00±0.82	9.22±0.83	8.71±0.82	9.17±0.41
Manual dexterity	5.48±1.16	5.84±1.17	5.90±1.04	6.39±0.98	6.62±0.65	6.33±1.12	7.07±0.78	6.50±0.84
Bilateral coordination	6.72±0.74	7.00±0.00	6.90±0.3	7.00±0.00	6.69±0.63	6.89±0.33	6.93±0.27	7.00±0.00
Balance	7.44±0.92	7.89±0.46	7.90±0.3	7.89±0.32	7.85±0.55	7.89±0.44	8.00±0.95	8.00±0.00
Running speed and agility	8.12±0.83	8.00±1.15	7.81±1.25	8.17±1.10	8.38±0.77	8.22±1.58	8.57±1.08	8.17±0.41
Upper-limb coordination	8.00±2.47	7.37±2.54	9.45±1.86	9.33±1.75	10.08±1.93	11.00±1.58	11.14±1.35	10.17±2.23
Strength	8.36±1.52	7.84±2.12	7.55±1.86	8.72±1.63	8.62±1.76	8.67±2.18	9.43±2.10	8.00±0.89
Total motor score	65.40±9.8	65.32±10.35	66.27±9.67	69.06±9.44	70.69±8.08	71.56±7.82	73.29±8.52	70.33±6.41

Working memory

Table 3 demonstrates the average and standard deviations in subtests of forward and backward digit span and visuomotor construction for the variables of the study which divided males and females into 4 grade groups. The results show that grade 1 girls had the maximum digit forward standard score; 11.28 (2.02) whereas grade 1 boys had the minimal digit forward standard score; 9.92 (1.58). For digit backward, grade 3 girls showed the maximal digit backward standard score; 5.11 (2.47). On the contrary, grade 2 boys showed the minimal digit backward standard score; 3.00 (1.00). The last variable was visuomotor construction. The results presented that grade 3 girls used the highest time; 45.44 (46.05) whereas grade 4 boys spent the lowest amount of time; 8.93 (9.20).

Table 3 Mean±SD of working memory test.

Working memory tests	Grade 1		Grade 2		Grade 3		Grade 4	
	Boys Mean±SD	Girls Mean±SD	Boys Mean±SD	Girls Mean±SD	Boys Mean±SD	Girls Mean±SD	Boys Mean±SD	Girls Mean±SD
Digit forwards	9.92±1.58	11.28 ±2.02	10.81±1.83	10.56±1.42	10.38±1.66	10.89±2.76	10.92±2.53	10.16±1.32
Digit backwards	3.44±1.26	3.11±1.72	3.00±1.00	3.67±1.71	3.46±0.66	5.11±2.47	4.14 ±1.23	4.00 ±1.41
Visuomotor construction	32.2±34.1	32.98±38.27	34.64±34.75	30.88±41.04	12±15.02	45.44±46.05	8.93±9.20	26.77±24.59

Correlation-analysis of motor proficiency and working memory

The correlation analysis between total motor score of BOT-2 SF and working memory performance including digit span and visuomotor construction indicated significant positive moderate correlations between the motor proficiency performance and in digit span (0.512, $p<0.001$). There was significant correlation between motor proficiency and digit span (working memory) in school aged children, and there was no significant correlation between motor proficiency and visuomotor construction. There was also no significant correlation between digit span and visuomotor construction. Pearson's correlations between total motor score of BOT-2 SF and working memory performance are presented in Table 4.

Table 4 Pearson's correlations between Motor Proficiency, Digit Span, and Visuomotor Construction.

	Motor Proficiency	Digit Span	Visuomotor Construction
Motor Proficiency		0.512*	-0.131
Digits Span	0.512*		-0.036
Visuomotor Construction	-0.131	-0.036	

**p<0.001*

Discussion

In this cross-sectional survey study of grades 1-4 school aged children, the motor proficiency and working memory performance were measured. Descriptive statistics showed that grade 4 boys had the maximum total motor proficiency score whereas grade 1 girls had the minimal total motor proficiency score. Agreeing with previous studies shown the effect of age category on the level of motor proficiency was different among age groups.[27, 28] Our findings of this study also revealed that motor skill increased with age. In previous and similar studies, it was also found that motor developed with increased age.[29] Our results indicated that there were no differences with regard to gender effect on motor proficiency measured by BOT-2 SF. In contrast, the differences between boys and girls were reported, girls were better than boys in balancing backward, stand and reach, and jumping sideways. The only gender difference in motor abilities among subjects was in a coordination test whose outcome favored boys. This contradicts the study of Roth et al.[30] mentioning gender difference favoring boys only in running tasks. In general, this comparison has to be considered with caution because different tests are used.

Moreover, the gender and age differences were determined in working memory test results of this study. The maximum score of digit forward, digit backward and visuomotor construction were girls from grade 1, grade 3 and grade 3, respectively. In previous and similar studies, it was also found that cognitive abilities developed with increased age.[29] Our results indicated that there were no differences with regard to gender effect on working memory in all tests, whereby the subject aimed to remember the number sequences in both forward and backward order while the phonological loop and visuomotor construction required visual-spatial working memory. This contradicts the study of Jansen et al.[31], the gender effect for working memory shows mixed results as boys performed better in the Corsi Block-Tapping Test forward and girls performed better in the Digit-Span Test forward. Both tests were designed to retrieve information of different parts of working memory, i.e., remembering the sequences in the same order (forward) measures the phonological loop, whereas the Corsi Block-Tapping Test forward requires visual-spatial working memory, whereby the subject aimed to remember the number sequences in both forward and backward order while the phonological loop and visuomotor construction requires visual-spatial working memory. Previous studies found that boys showed better performance than girls in all motor variables.[32] Alternatively, Jansen et al.[31] showed the girls performing better in the digit span test forward which indicated that girls generally had a better auditory working memory ability than boys.

In this study, the relation between the motor proficiency and working memory was also determined. The moderate correlation between total motor proficiency standard score and standard score of working memory tests (digit span) was revealed. Regarding the relation of motor performance and working memory which is an important consideration when planning classroom activities to achieve optimal working memory. This outcome is a core aspect of executive functions to achieve learning ability for children within the school environment. The relationship between gross motor skills and working memory as executive functions is often described as an overlap in brain regions between the frontal, parietal, and motor cortices that are important for both gross motor skills and working memory.[33] These relationships are supported by recent studies indicating that the better the motor skills, the better the processes of preparation and attention, which are mainly stimulated the premotor and motor cortex and also the fronto-parietal system during a task using working memory.[34] Our study have also revealed a significant correlation between motor proficiency scores and digit span with verbal working memory in school-aged children. Cross-sectional behavioral studies have shown that gross motor skills are related to verbal working memory,[13, 35] whereas contradictory studies reported a similar relationship with visuospatial working memory.

Based on both theory and evidence, there is a continuous interest in understanding the specific relation between motor skill and working memory. The insights obtained by our study will help to understand the specificity of relations between motor skills and working memory, which will be a useful guideline for practical applications that benefit school-aged children. Some evidence also indicated the importance of individual working memory capacity on the child's ability to obtain information and new skills.[36] In a typical child, working memory scores can predict reading ability[28] and mathematical achievement. Currently, in school settings, usually the only primary focus of learning is to develop students' academic skills especially in numeracy and literacy. Consequently, there may be less given time in the school curriculum for encouraging the physical development of students, which supports the acquisition of motor proficiency towards physical activity in school.[37] Moreover, previous cross-sectional surveys suggest that only approximately 23.4% of Thai children and youth met recommended levels of physical activity.[21]

Recent studies, including the correlation between motor tests and working memory tests, have been conducted on 3 to 6-year-old children[38] and the significant relationship between cognitive variables and academic performance have been reported for school-aged children.[39] Additionally, motor proficiency appears to be associated with cognition, which underscores the importance of early motor skill development of children.[37, 40] The above-mentioned studies suggest that a curriculum which focusses on a child's physical activity to enhance motor proficiency may benefit neurodevelopment relevant to specific executive function such as working memory and can therefore improve academic achievement over time. More supportive evidence of correlation between school-aged children's motor proficiency and working memory may help develop important guidelines on how to plan curriculum or planning classroom activities in a school setting.

Limitations

Although this study provides correlation evidence between motor proficiency and working memory, it also has several limitations. First, participants were selected from only 4 schools in Bangkok metropolitan, which further impacts the generalizability of findings to Thai school-aged children. These issues will need to be addressed by future studies in order to extend throughout regions in Thailand. Second, this current study addressed the tests of working memory by digit span task which is well-known as the common tool even this test lacks of the study in psychometric properties. In the part of the visuomotor construction, it is the informal test adopted from the DOTCA-Ch which can be measured visual short-term memory. A research recommendation for the future is to use the outcome measures that can assess the visual working memory such as picture span test, simple object span test or word span test. Lastly, we did not assess other executive functions (e.g., attention, cognitive flexibility) that may be important for motor proficiency so the next study must consider other aspects of these parameters.

Conclusion

The results of this study found the age differences in motor proficiency and working memory performance. Moreover, there are a significant correlation between motor proficiency and working memory in Thai school-aged children. It was also found that children with high levels of motor proficiency had better performances in working memory than participants with low levels of motor proficiency. The benefit of this study was to demonstrate the association between motor proficiency and working memory. This can lead to blending motor skill with cognitive skill activities within the school curriculum that may benefit school-aged children.

Conflict of interest

The authors declare no conflicts of interests.

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