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Research Article

The Association between Fine and Gross Motor Skills with Cognitive Control and Academic Performance in Adolescent Students

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Abstract

Background: Former studies mostly focused on the correlation of motor coordination with physical health, while this ability would be associated with mental health and certain determining performances, such as academic achievement. Hence, the purpose of this study was to investigate the relation between fine and gross motor coordination with cognitive control and academic performance.
Methods: For this purpose, we studied 87 adolescent girl students, aged 13 to 15 years old, in the first grade of high school from Qeshm Island. The Pegboard and Star excursion balance tests were utilized to assess fine and gross motor coordination and the Stroop test for cognitive control. In addition, we considered the grade point average as the academic performance. For data analysis, the correlation and regression were used.
Results: Results indicated a significant negative relation between fine motor performance with non-dominant hand and error in incongruent trials (r=-0.21, P=0.0496). Moreover, there was no direct significant relation between motor and cognitive components with academic performance. However, a significant negative relation was observed between age, academic performance (r=-0.23, P=0.03) and balance performance (r=-0.38, P=0.0001), as well as a significant direct relation between the interference score and age (r=0.21, P=0.04).
Conclusion: Based on the present findings, it seems that fine motor control of non-dominant hand has a common origin with inhibition. Additionally, considering the similar downward trends in the three components of academic performance, interference control, and balance as a result of the increase in age, it seems that age would be a determining factor in examining the relation between cognitive, motor, and academic performance.

Keywords: Academic performance, Executive functions, Motor skills

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1. Introduction

Numerous studies have examined various aspects of individuals' performance, especially adolescents, including educational, cognitive, and motor performance. These functions, on top of their role in people's health and well-being, could affect their future success. Academic achievement is one of the concerns of the greatest importance among educational authorities and families, especially in adolescence. Therefore, researchers are looking for factors that influence academic performance to optimize it. Recently, examining the relation between physical fitness and motor skills and academic performance has attracted a great deal of scientific attention (1).

Motor skills are essential for reaching the optimal performance in many tasks, which are usually classified into two types of fine and gross skills based on the size of the muscles that involve in movements. Fine motor skills include the movements that need a high degree of control in the small muscle like manual dexterity, while gross motor skills are those requiring large muscle groups such as jumping, walking and balance task (2). There are paradox evidence that imply the relation between physical fitness and motor skills with academic performance (3). In this regard, it seems that cognitive functions are essential components of academic performance and since physical fitness appear to be related to cognitive functions, it could be assumed that the relation between physical fitness and academic performance may be influenced by them (1).

Cognitive control is an essential function in daily life as well as academic performance, particularly in adolescence. Cognitive control consists of a set of higher-order cognitive skills, which are responsible for monitoring (such as conflict monitoring) and compensatory adjustments (including inhibition and interference control) that are important in successful targeted behaviors (4). Inhibitory control (one of the components of cognitive control) involves the ability to control one's attention, for instance ignoring irrelevant stimuli, thoughts, or emotions. Inhibition control enables us to change and choose how we react and how we behave (5). Researches have shown that there is a relation between this component and motor skills (6), and this association might be due to the common involved brain area (7), the same development timetable (8) and similar underlying process between cognitive and motor skills (9).

Most of the previous studies have examined the impact of physical exercise and motor training interventions on cognitive and academic performance. In addition, they have mostly emphasized on the relation between physical fitness like aerobic ability, but motor skills have been less directly addressed (1). However, the question is whether the proficiency in motor skills are related to cognitive and academic performance and which motor skills have a greater relation with them. Based on the literature, motor skills with higher information processing demands seem to be associated with higher educational and cognitive performance (10). Schmidt and colleagues concluded that muscular strength, aerobic capacity and motor coordination were related to executive functions, but the only factor whose relation to academic performance was affected by the role of cognitive functions was motor coordination (11). Motor coordination is defined as a series of learned movement sequences which are performed simultaneously or consecutively (12). In this regard, fine coordination and balance movements seem to be among the components associated with cognitive and academic performance (7). For instance, Pate and colleagues revealed that fine motor skills are contributed to individuals' mathematical skills (13). However, there have also been studies that did not observe such a relation. For example, Gaysina, Maughan, and Richards concluded that the relation between fine motor skills and academic performance was observed only in individuals with low levels of cognitive performance (14). In addition, Rigoli and colleagues demonstrated that among the components of motor coordination, balance, throwing, and catching, only throwing and catching were of a significant relation with academic performance and working memory in adolescents (15). Given the inconsistency in the previous findings, it is necessary to continue this research issues.

In addition, the past studies have focused more on childhood, while adolescence is a critical and transitional period between childhood and adulthood, and many of the physiological and psychological status of this period could provide great deal of information about the individuals' future (16, 17). Concerning adolescence, there is a gap between emotional development and cognition and behavior, which makes it a risky period. During this period, people are more likely to take risks and the emotions and behaviors are less regulated (17). On the other hand, many health lifestyle-related behaviors and habits such as physical activity are formed during this period. Pate and colleagues reported a 4% decrease in moderate to severe physical activity based on physical activity measurement system and a 6-13% decrease based on self-report scale in adolescent girls between sixth and eighth grades (18). Moreover, from a neurocognitive point of view, Adleman and colleagues showed that the role of prefrontal cortex in the Stroop task performance has not yet reached its final stage in adolescence and continues to develop into adulthood (13).

As mentioned before, few studies have examined the relation between motor skills with academic and cognitive performance, most of which have emphasized on physical fitness components rather than motor skills. In addition, certain studies have reported conflicting results regarding the relation between motor skills and academic performance. They have focused only on fine or gross motor skills as an index of motor coordination whereas each of these kinds of skills can play a different role in this regard. On the other hand, most of the researches have focused on childhood stage, while adolescence is also a critical period for examining these components. Accordingly, considering the importance of cognitive control and academic performance in adolescence and its relation with motor components, the present study seeks to investigate the relation between these three variables in order to answer the question whether there is a relation between fine and gross motor coordination, and the cognitive component of interference control and academic performance. In addition, given the rapid and mutational changes in adolescence, it is interesting to look at how these components change over the ages of 13 to 15 years.

2. Methods

In the present study, we employed the correlational and cross-sectional research design. All procedures were in accordance with the ethical standards of University of Mazandaran.

2.1. Participants

The sample size was calculated using G-power software version 9.13 (α=0.05, 2 tails, Power=0.8, r=0.3) (19). Participants included 90 female students studying the first grade of high school (from Qeshm Island) aged between 13 to 15 years, with 30 people of other school grades attending (13 years old, seventh grade, 14 years old, eighth grade, 15 years old, ninth grade); however, 3 of the 15-year-old group withdrew from the study. After giving the initial instruction about the study, informed written consent was obtained from all participants. All of them participated in this study voluntarily. Participants were selected based on the inclusion criteria. Inclusion criteria included right-handedness, no medical prohibition to exercise, and no color blindness. Furthermore, in order to match the age of the participants, only those were selected who were born in the first half of the year (Jalali or solar Calendar) in each academic grade.

2.2. Tools

2.2.1 Fine Motor Skill Measurement

The Pegboard test is a neuropsychological test of manual dexterity and manual coordination. This test was applied to evaluate fine motor skill. The assessment tool consisted of a rectangular board with 25 holes which were placed directly in front of the participants on the table and subjects had to place the pins in the holes as quickly as possible. The number of pins placed in the holes within 30 seconds was counted. Subjects performed each step of the test three times with their right hand and three times with their left hand and the score of each hand were calculated separately (20).

2.2.2 Balance Measurement

The Star excursion balance test (SEBT) was used to evaluate the balance. The test consists of a board of 8 lines in different directions with a 45 degree angle. The participants must maintain their balance on one leg, while using the other leg to reach as far as possible in each direction. Six practice trials were performed on each limb for each direction. On the examination trials, the most distal location of the reach foot was recorded. All trials were completed in one direction before moving to the next. Following the measurements, the mean of the maximum reach distance in all directions was divided by the person's leg length and multiplied by 100 to determine the dynamic balance score (21). Based on the definitions provided for gross motor coordination, this test, in addition to requiring power and balance, requires also gross motor coordination with accuracy (22).

2.2.3 Stroop Test

The computerized version of the Stroop test was employed to evaluate the interference control and inhibition. The four colors of green, yellow, blue, and red are used in this test, which are identified using color labels on the corresponding keys. In this test, the stimuli are divided into two congruent and incongruent conditions that are randomly presented during the task execution. In congruent trials, the name and color displayed were similar (for example the word blue is displayed in blue), but in incongruent trials, the color name was in contrast with the color displayed (for example, the word blue is shown with yellow ink). In both of these trials, participants have to respond to the word color regardless of the meaning of the word. In this test, we recorded the number of errors and correct responses and the reaction time in congruent and incongruent trials, interference score (difference between the number of errors in congruent and incongruent trails) and interference time (reaction time difference between congruent and incongruent trails) (13).

2.3. Procedure

Primarily, information about the study and experiment process steps was provided for students and their parents. After obtaining their consent, all participants completed the self-reported questionnaire about their health status and medical history. Subsequently, based on the mentioned inclusion criteria, participants were selected. In order to prevent the effect of fatigue on the task performance, the participants went to the lab for motor and cognitive assessment in two separate days. In the first session, the Pegboard and the star excursion balance (SEBT) tests were administered in order to assess fine and gross motor coordination, while the inhibitory and interference control was evaluated through the stroop test in the second day. To assess academic performance, as in other studies, the average of course scores at the end of the academic year or the grade point average (GPA) was used (23). The Pearson correlation and linear regression tests were used in order to investigate the relation between variables. All the data were analyzed with PASW (SPSS) 18 software at the 0.05 level of significance.

Table 1: Means and standard deviations of the test variables in seventh, eighth and ninth grades

Groups / Variables	Star Balance Test (points)	Fine motor skill right hand (Frequency)	Fine motor skill left hand (Frequency)	GPA* (Score)	Interference score (Frequency)	Interference time (millisecond)	Error congruent trails (Frequency)	Error incongruent Trails (Frequency)	Reaction time congruent trails (millisecond)	Reaction time incongruent trails (millisecond)
13 years old, seventh grade	68.40	16.87	16	19.30	-0.16	33.76	0.50	0.40	871.83	**876.93**
14 years old, eighth grade	57.66	17.43	16.30	18.83	0.13	13.96	0.73	0.66	804.86	**839.16**
15 years old, ninth grade	54.59	19.33	17.30	18.70	1.50	18.25	1.15	2.50	868.81	**865.85**
Mean	60.41	17.83	16.52	18.95	0.46	22.12	0.93	0.77	847.80	**860.47**
Standard deviation	15.10	2.75	2.78	1.07	3.10	35.10	0.25	1.30	118.50	**148.70**

*Grade Point Average

3. Results

The Participants were in three age and educational categories. Thirty of them were 13 years old and in the seventh grade, thirty of them were 14 years old and in the eighth grade, and twenty seven of them were 15 years old and in the ninth grade. The mean weight of the students was 43.11 (SD=8.06) and the mean height of them was 154.95 (SD=5.76). Table 1 represents the mean and standard deviation of the test variables showing the total scores of individuals in each of the variables.

Afterwards, in the next step, the results of the correlation coefficient between the variables of cognitive and academic performance with the variables of balance and fine motor coordination were evaluated and the regression test was used in the variables where the correlation was observed. To run each of the regression tests, its assumptions including the linear relation between variables, auto-correlation in the residuals, and normal distribution of errors were examined. The regression model was then analyzed. According to the results, the only significant relation observed was between fine motor coordination of non-dominant hand and the number of errors in incongruent trials (r=-0.21, P=0.0496). Accordingly, individuals with higher performance in pegboard test had fewer errors in incongruent trials. The regression components of this variable are presented in Table 2.

The findings of the correlation test in other components implied that there were no significant relation between variables of balance and fine motor tests with other components of Stroop test and academic performance (P>0.05). However, the results of the correlations between grade (age) and motor, cognitive, and academic performance showed that the same trend of changes were observed in the GPA, balance and interference score. According to the results, there was a significant negative relation between grade (age) and academic performance (P=0.03, r=-0.23). Thus lower academic performance was achieved in the higher grades. In addition, the results indicated that the interference score was significantly correlated with grade or age (P=0.04, r=0.21). Moreover, the findings showed that there is a significant negative relation between the grade (age) and the star excursion balance score (P=0.0001, r=-0.38). According to the above-mentioned results, with the increase in age, balance scores of adolescent girls in the star balance test decreased. Table 3 represents the components of the regression test in academic performance, cognitive function and balance Score.

Table 2: Regression results between incongruent trials errors and non-dominant fine hand motor skill

Model	Unstandardized coefficients		Standardized Coefficients	t	sig
	Standard error	B	Beta		
Constant	0.16	1.25		7.69	0.00
non-dominant fine hand motor skill	0.01	-0.02	-0.21	-1.90	0.05

Table 3: Regression results between age (grade) and academic performance, Interference score and balance Score

Criterion variables	Unstandardized coefficients	Standardized Coefficients	Unstandardized coefficients		t	Sig
		B	Standard erorr	B		
Academic Performance	Constant		1.13	21.37	19.20	0.00
	Grade (age)	- 0.23	0.14	-0.30	-2.10	0.03
Balance	Constant		14.95	115.96	7.75	0.00
	Grade (age)	-0.37	1.86	-6.93	-3.75	0.00
Interference score	Constant		3.27	-6.17	-1.88	0.06
	Grade (age)	0.21	0.40	0.83	2.03	0.04

4. Discussion

This study aimed to investigate the relation between the two kinds of motor skill with the cognitive component of interference control and academic performance of adolescent girl students in three ages and educational grades. Examining the relation between motor and cognitive components, only one relation was observed between the non-dominant hand's fine motor performance and the number of errors in incongruent trials. Accordingly, as the non-dominant hand's fine motor performance increased, the error rate in the incongruent trials decreased. In this regard, the number of errors in incongruent trials could also be considered as an indicator of the inhibitory control. Hence, based on the present findings, there is a relation between fine motor coordination and inhibitory control. This result is in line with the results showing that fine motor skills under time pressure are associated with cognitive performance (6). However, it seems that the common brain areas between fine movements and inhibitory control can justify this result (7). According to the Cognitive Stimulation Hypothesis, movements with non-automatic execution and the need for higher coordination involve areas of the brain that are used to control higher-order cognitive processes (11), thus performing fine motor skills with non-dominant hand may have this feature (9). One other reason that might explain the relation between these two components is the sharing of speed and accuracy in both cases. However, the major ambiguity which remains unanswered is that non-dominant hand movements might require more cognitive ability, so individuals with greater cognitive ability can control it, and the other unanswered question is whether improved fine motor control could lead to increased cognitive control, or people with higher cognitive control can control fine motor movements more efficiently with non-dominant hand. Further research could answer these questions. It is noteworthy, however, that the Stroop test was performed with the subjects' dominant hand, while this component was related to the performance of their non-dominant hand movements, the left hand, which may indicate a common cognitive origin for the two types of tasks rather than their shared motor demands.

Moreover, despite the relation between fine motor performance and inhibition control, this relation with academic performance was not observed, while some studies have observed it (15). For example, Pitchford and colleagues showed that fine motor skills are correlated with academic performance (24). However, this relation was not observed in the present study. Van der Fels and colleagues stated that there is a relation between motor and cognitive skills in pre-adolescent children, which is observed less in post-adolescent children. The power of the relation between motor and cognitive skills reduced in older children (6). This fact can be justified assuming that the timetable of cognitive and motor processes accelerates between 5 and 10 years (8), and after that, it seems that these features would be independent of each other.

There was no direct significant relation between the academic performance and the cognitive and motor components mentioned above. There is also studies by Schmidt and colleagues demonstrating that there is no significant relation between motor skills and academic performance, yet this study showed that cognitive ability could play a mediating role in this relation (11). Even though the results of the present study did not reveal a relation between academic and motor performance and the mediating role of cognitive function, the trend of these components' changes as a result of the increase in age was similar. Based on the current findings, it seems that there is a descending similar trend between academic performance, balance, and inhibition scores in adolescence, and this similarity may be considered as an indicator. The results showed that there is a significant negative relation between age and academic performance, which means that lower grade point average was obtained in higher grades. The pattern of decreasing the GPA based on the increase in the grade may seem logical, because as grades increase, usually courses become more difficult. However, the important point was that this negative relation was also observed in two other cognitive and motor components. The decrease in the interference and inhibitory control with the increase in the age of girls in this age group may be due to the emotional challenges associated with this age (17), although future research should address this issue directly. In addition, as mentioned, sedentary lifestyle and less physical activity may also trigger the decline in motor components (18). Consequently, although no significant relation was observed between these components, the trend of change in the different grades was almost the same, and the three components of academic performance, inhibition, and balance had the same descending trend in different ages.

The relation between the changes in balance and cognitive and academic performance could be regarded from two perspectives (25); firstly, the role of the cerebellum in balance as well as its role in cognitive functions could be mentioned (7, 12); secondly, considering the balance test used in this study, which also examines gross motor coordination, the role of motor coordination in cognitive function could be noted (11, 15, 26). Schmidt and colleagues and Rigoli and colleagues have shown that cognitive performance is a mediator of the relation between motor coordination and academic performance, however, Rigoli and colleagues employed working memory as a cognitive component and Schmidt and colleagues showed this finding in different age samples (11, 15).

Additionally, the current findings could be considered from the physical fitness perspective. In this regard, it seems that during the time of puberty to late adolescent, the sex hormone level changes may result in the increase in body fat percentage (27), thereby reducing girls' ability for motor performance. An increase in fat percentage during this period is generally negatively correlated with motor skills that are contributed to body weight. Previous researches have also conveyed that the relation between fat percentage and physical fitness was higher in girls aged 10-17 years than in girls aged 7-9 years (28). This physiological state along with a decrease in the tendency of girls to have an active lifestyle and participate in physical activities are usually the reasons for the decline in motor performance in adolescent girls as a result of age (18, 27, 28). There are other studies indicating that girls' balance also declines markedly from childhood to adolescence (28). According to Pate and colleagues, in adolescence, girls between the sixth and eighth grades have a reduction in moderate to severe physical activity (18). The results of the secular trend also represent that the decrease in motor coordination and physical fitness is in line with the decrease in physical activity level (29, 30). In the neurocognitive studies, there are also evidence that reveal a negative correlation between body fat (31), lack of physical activity (32) and poor physical fitness (23) with cognitive functions. In this regard, it seems that decreasing physical activity and physical fitness and consequently, motor performance (or vice versa) along with emotional and physical changes during adolescence, decrease cognitive functions and, as a result, academic performance. However, future researches should address this idea directly.

5. Conclusion

In general, the present findings only shed light to the relation between non-dominant hand fine motor skill and inhibitory control and did not show a direct relation between the fine and gross motor skills with academic performance. However, the changes trend was similar in gross motor skill, cognitive function and academic performance as a result of the increase in age and school grade. Thus, it seems that age could be a pivotal factor in the relation between different motor, cognitive, and academic components. It should be noted, however, that the present study was a cross-sectional research and that future research could be conducted longitudinally in order to accurately respond to this hypothesis. In addition, further research could examine changes in cognitive and academic components through the interventions based on balance and non-dominant hand fine motor training.

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Ethical Approval

The present study was approved by the University of

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