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The Mediating Role of Executive Functions in the Relationship between Motor Skills and Academic Achievement in Children with Learning Disabilities: A Descriptive Study

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Original Article

Abstract

Introduction: Motor skills deficits are of the problems that children with learning disabilities face. The aim of this study was to investigate the relationship between motor skills and academic achievement in children with learning disabilities mediated by executive functions.

Materials and Methods: Participants were 182 children with learning disabilities from Isfahan City, Iran, who were included using convenient sample strategy. Fine and gross motor skills were evaluated using Bruininks-oseretsky-2 Test, academic achievement was measured using Kaufman Test of Educational Achievement, and executive functions was assessed using Behavior Rating Inventory of Executive Function 2 (BRIEF2). The analysis was performed by structural equation modeling.

Results: The results showed the significant direct effect of gross motor skills on academic achievement (P = 0.001) and the lack of direct effect of fine motor skills on academic achievement (P = 0.735). The Structural Equation Modeling (SEM) analysis showed that gross (P = 0.001) and fine (P = 0.048) motor skills had a positive effect on the academic achievement of children with learning disabilities through an indirect path and through executive functions.

Conclusion: The fundamental importance of motor skills in the academic achievement of children with learning disabilities can be emphasized. The present study also emphasizes the importance of executive functions in the academic achievement of children with learning disabilities, as executive functions mediate the relationship between motor skills and children's academic achievement with learning disabilities.

Keywords: Learning disabilities; Gross motor skills; Fine motor skills; Executive functions; Academic achievement

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Introduction

Research on motor behavior has shown that body movements play an important role in children's cognitive skills (1). According to the Piaget theory, the expanding range of motor behaviors that a child develops during the first years of life is essential for achieving advanced cognitive abilities; Because creating sufficient motor control allows the child to interact with the living environment and learn from it (2).

In recent years, interest in the role of motor skills in children's educational achievement has increased (3). The results of studies show that motor skills are related to educational achievement (4). For example, it has been indicated that children with developmental coordination disorder (DCD) may have more educational problems compared to children without motor problems (5), and other studies have suggested that children with learning disabilities (LDs) have lower motor skills than their normal peers (6,7). In addition, compared to other children, these children show poorer educations performance despite normal intelligence quotient (IQ) and being in a suitable

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educational environment and lack of obvious biological lesions (blindness, deafness, motor disability, and retardation) and the absence of acute social, economic, and psychological problems (8). These children are deficient in one or more areas of educational achievement such as reading, math, and writing (9). Children with learning disabilities face problems in reading words correctly, speed and fluency in reading, and oral comprehension, children with writing disabilities face problems in spelling, grammar accuracy, punctuation, and clarity and systematic expression of speech, and children with math disabilities face problems in understanding the concept of numbers, memorizing the rules of mathematics, accuracy and fluency of mathematical calculations, and reasoning (9).

Given the investigations, the lower the skill in a motor area such as fine motor skill (FMS) and gross motor skills (GMS), the greater the learning delay in a particular area of educational performance (5,10). Additionally, it was observed that FMS and GMS have a positive relationship with several aspects of cognitive functions and with educational performance in mathematics and reading (10). The results of a study by Westendorp et al., which examined the relationship between GMS and academic achievement in children with LD, revealed that there was a correlation between reading and mobility skills and between mathematics and object control skills in children with LD (5). In summary, previous research has illustrated that the better the GMS, the better the cognitive function, and in children with LD with underlying academic skills problems, adequate development of motor skills may be important to promote the academic skills development (7).

Despite the above evidence, the nature of the specific relationships between children’s motor skills and academic achievement is still unclear and this relationship is debated (11). Therefore, instead of examining a general relationship between motor skills and LD, it seems that specific relationships between different subsets of motor skills (GMS and FMS) and educational achievement in children with LD should be examined (5). On the other hand, in most studies, the strength of the relationship between motor skills and academic achievement has been evaluated with correlation methods, however these methods do not indicate whether this relationship is direct or indirectly mediated by other factors such as higher-level cognitive abilities such as executive functions (EFs) (11).

EFs are generally defined as a set of high-level cognitive abilities responsible for purposeful behaviors, problem solving, and flexible responses to environmental demands (12). EFs are an important indicator of school readiness that has been reported to be important for academic achievement in studies (13), and even if there is not yet a proper theoretical framework to clarify the relationship between motor skills and academic achievement, EFs seem to be a potential choice to mediate this relationship (14); Because EFs stands for a structure consisting of several distinct and yet interconnected cognitive processes that are responsible for controlling and organizing directional behaviors and can affect both sides of this relationship (15).

On the other hand, although motor skills and EFs have been found to be associated with academic performance (16), very little effort has been made to address the interactions among EFs, motor skills, and academic performance (17). A recent study of a typical population of children between the ages of 10 and 12 found that motor coordination skills had an indirect effect on mathematics, reading, and writing skills through the EFs’ abilities in inhibition, working memory (WM), and cognitive regulation (18).

Despite the above investigations, few studies have examined the simultaneous relationship between motor skills (GMS and FMS) and EFs to predict the academic achievement of children with LD. Therefore, in order to investigate the relationship between GMS and FMS on academic achievement in children with LD and to investigate the mediating role of EFs in this regard, a mediating model was developed and tested. To develop this model, it was hypothesized that GMS and FMS have a direct positive effect on the academic achievement of children with LD. Moreover, it was hypothesized that GMS and FMS have a direct positive effect on EFs through a direct path, EFs have a direct positive effect on academic achievement of children with LD, EFs have a positive mediating role on the relationship between GMS and FMS on the academic achievement.

Such a study can provide insight into the possible relationships between motor skills and cognitive domains of child development in this vulnerable population. In addition, it can provide guidelines for formulating education policy regarding education in primary schools with special needs.

Materials and Methods

This was a descriptive-correlational study with structural modeling that was conducted in the spring of 2021 in Isfahan, Iran. The participants of the study were male and female students with an age range of 7 to 12 years, who were referred to the Learning

Disorders Centers in Isfahan in the second half of the school year 2020-2021 and were diagnosed with LD by the specialists of the centers. After obtaining permission from the Education Department and coordination with the directors of the Learning Disabilities Centers and holding an online coordination session for the parents and explaining the study, the volunteers were selected using the convenience sampling method. For each volunteer, individual records were reviewed at the centers, which contained information about the child's characteristics (such as age, gender, and IQ), short medical history, and comorbidities. The study inclusion criteria included having a normal IQ (greater than or equal to 70) (9) using Wechsler Intelligence Scale for Children-4th Edition (WISC-IV) (19), having LD (learning disability in mathematics, reading, and writing), and minimum literacy for parents. Existence of physical and motor problems, visual and auditory disorders, having a comorbid disorder such as DCD, mental health problems, and taking certain medications were also considered as the exclusion criteria. The research plan was approved by the ethics committee of the Khorasgan Branch, Islamic Azad University and all students and their parents read and signed the informed consent form before the test.

In the present study, the structural equation method was used to evaluate the model fit, but there is no general agreement on the optimal sample size in studies that use the structural equation modeling method. Gall et al. estimated the sample size to be at least 15 units for each predictor variable in multivariate regression analysis (20). Since the structural model is in some respects completely consistent with multivariate regression, 15 units for each variable measured in the structural equation model seems logical (21). On the other hand, Hooman recommended a sample size of 5 for each free index (not each variable) in the structural equation model (21). Considering that in the present study, there were 12 observed and latent variables in the design pattern that were the basis for sample selection, the sample size of about 180 people seemed to be sufficient. Given the probability of drop of the subjects, 200 people were considered. Examining the individual case of each child in the centers, 7 people due to non-compliance with the IQ inclusion criterion and 11 people due to non-compliance with the exclusion criteria and having a comorbid disorder [including 7 children with DCD and 4 children with autism spectrum disorder (ASD)] were excluded from the study and finally, 182 participants were selected.

The Kaufman Test of Educational Achievement-3rd Edition (KTEA-III) was employed to assess academic achievement, which assesses the reading, writing, and mathematics skills of children, adolescents, and young adults. The test-retest reliability was reported to be 90% for oral expression and 95% for written expression (22). The test consists of 9 main tests and 19 subtests, of which 7, 7, and 5 subtests are for reading, writing, and mathematical concepts and calculations, respectively (23).

The Bruininks-Oseretsky motor proficiency test was utilized to assess motor performance, which assesses the motor performance of children aged 4 to 21 years. The complete set of this test consists of 8 subtests (including 46 separate sections) that measure motor proficiency in GMS (four subtests) and FMS (three subtests). The test retest reliability and validity of the test were 0.87 and 0.84, respectively (24). Besides, the test and inter-rater reliability coefficients of the test were respectively 0.8 and 0.9, indicating that the scale is reliable and valid for measuring GMS and FMS (25). The scoring method of the test was based on the test guide table developed by Bruininks et al. (25).

The parent version of the Behavior Rating Inventory of Executive Function (BRIEF) questionnaire, designed by Isquith et al., was applied to assess EF, and it was used here to assess the executive functions of children aged 6 to 12 years. The tool consists of 63 items and 3 indicators, each of which includes scales: behavior regulation index including inhibition and self-monitoring scales, emotion regulation index including attention shift and emotion control scales, and cognitive regulation index including scales of initiation, WM, planning, task monitoring, and task organization (26). The reliability of the questionnaire in studies was reported between 0.82 and 0.98 and its retest reliability was 0.72 to 0.84, suggesting a good reliability for the questionnaire (26). The reliability of the Persian version of the questionnaire was reported to be 0.93, which indicates that the BRIEF questionnaire has a good validity as a tool for measuring EF and can be used as a valid tool in research and clinical work (27). The scoring scale of this questionnaire is as three scores, and one of the options of "often, sometimes, and never" is chosen for each item that receive scores of 3, 2, and 1, respectively, and a higher total score indicates more weakness in EF (26).

To participate in the study, the students and one of their parents attended the designated hall in the city of Isfahan according to the previously specified schedule and with a time interval of 30 minutes with other participants. The students were first taken the KTEA-III test for about 35 to 40 minutes by a specialist in a designated room, and after a 5-minute rest, the

Bruininks-Oseretsky test was taken for about 35 to 45 minutes at 8 stations. In the fourth station, the students received 10 minutes of rest and nutrition, after which they completed the remaining four stations. All steps were the same for all participants in terms of order and rest time. At the same time as the tests were performed by the students, their parents completed the BRIEF questionnaire at the designated location. In total, each student spent about 100 to 110 minutes in the hall with their parents.

For descriptive analysis of data and examining the internal consistency (IC) of the variables, the SPSS software (version 23, IBM Corporation, Armonk, NY, USA) was utilized, in addition, taking into account the single-item variables in the study model, the Smart PLS software (Partial Least Squares. Version 3.0 M3. Ringle, Wende & Will 2005. Hamburg, Germany) was used to model the structural equations (28).

The models presented in the study included measurement models and structural models, with the former ones examining the relationship between latent variables and their representatives. In the structural model section, the relationship between latent variables is shown (29). The validity and reliability of measurements are essential criteria in determining the accuracy of measurement models. Since reliability is a prerequisite for validity, first the reliability of each variable was evaluated using indicator reliability, composite reliability, and Cronbach's alpha coefficient. The indicator reliability indicates the reliability of the representatives for a structure in which the coefficients and factor loads should all be higher than 0.4 (29).

The validity of the variables was examined in the measurement models section using convergent validity and discriminant validity. In order to evaluate the convergent validity, the average variance extracted (AVE) criterion is used, which shows the degree of correlation of a construct with its indices (29). The Fornell-Larcker criterion was applied to evaluate the discriminant validity. This coefficient shows the relationship between a construct and its characteristics in comparison with the relationship between that construct and other constructs. Divergent validity is at an acceptable level when the amount of AVE for each construct is greater than the common variance between that construct and other constructs in the model (29).

If the fit of the measurement model is confirmed in terms of validity and reliability, in the next step, the predictive capabilities of the model and the relationships among the constructs of the structural model should be evaluated. Bootstrapping was used to evaluate the significance of the coefficients. Significance level of 0.05, confidence level of 95%, and critical value of 1.96 were considered in the significance of the coefficients.

To study the structural model, multicollinearity criteria can be used using variance inflation factor (VIF Inner), determination coefficient (R_2), and effect size (f_2). The multicollinearity criterion is used when the model has two or more predictive or independent variables (29).

Results

Based on the demographic characteristics of the samples, out of 182 participants, 95 and 87 were boys and girls with a mean age of 9.57 ± 1.82 and 9.37 ± 1.67 years, respectively. The descriptive findings of the variables and their IC are presented in table 1, which showed that the IC between the variables of GMS with FMS and between EF with GMS and FMS and between academic achievement with GMS and EF was significant at the level of 0.001.

The fitting indices of the structural model and its optimal value are presented in table 2. Reliability in the present model was above 0.4 and was confirmed. The Cronbach's alpha coefficient was higher than 0.7 in all constructs and composite reliability, which indicates the IC was also higher than 0.7 in all variables. Furthermore, since AVE in this model was higher than 0.5 in all variables, the convergent validity was confirmed.

Based on the data presented in table 2, each of the composite reliability indices and Cronbach's alpha in the study variables were higher than 0.7 and acceptable. Additionally, the AVE index in all variables was higher than 0.5. The Fornell-Larcker discriminant validity index was also higher in the variables than the correlation of the variables in the model. Thus, the measurement models had a good fit. In the study of structural model fit, the coefficient of determination in the variables of academic achievement and EF was 0.298 and 0.211, respectively, which was higher than 20% in the two variables.

Table 1. Descriptive findings and internal consistency (IC) of study variables

Variable	Mean ± SD	GMS	FMS	EF
GMS	39.31 ± 6.84	1		
FMS	35.03 ± 5.71	0.218^{**}	1	
EF	119.45 ± 14.72	-0.327^{***}	-0.22^{**}	1
Academic achievement	25.84 ± 3.15	0.387^{***}	0.141	-0.449^{***}

$^{***}P < 0.001$, $^{**}P < 0.010$, $^{*}P < 0.050$

SD: Standard deviation; GMS: Gross motor skills; EF: Executive functions; FMS: Fine motor skill

Table 2. Indices of fitness of the effect pattern of gross motor skills (GMS) and fine motor skill (FMS) on academic achievement mediated by executive functions (EF)

Indicators	Optimal value	GMS	FMS	Academic achievement	EF
R_2	-	-	-	0.298	0.211
R-Square adjusted	-	-	-	0.286	0.202
F_2	-	-	-	0.161	0.183
Composite reliability	Higher than 0.7	1.000	1.000	0.760	0.780
Cronbach's alpha	Higher than 0.7	1.000	1.000	0.780	0.802
AVE	Higher than 0.5	1.000	1.000	0.599	0.632
Fornell-Larcker	Above the correlation of latent constructs in the model with each other	1.000	1.000	0.632	0.657
VIF	Less than 2.5	1.24	1.05	-	-

GMS: Gross motor skills; FMS: Fine motor skill; EF: Executive functions; AVE: Average variance extracted

The effect size in the variables of academic achievement and EF were 0.161 and 0.183, respectively, which was reported to be close to 0.2 in both variables and was acceptable. The multicollinearity index in independent variables was less than 2.5 and acceptable. The effect model of GMS and FMS on academic achievement mediated by EF is presented in figure 1.

The results of direct and indirect effects of modeling are shown in table 3.

Based on the data in table 3, in the structural equation modeling, the effect of GMS on academic achievement as 0.272 (t = 3.42), the effect of GMS on EF as -0.390 (t = 5.75), the effect of FMS on EF as -0.172 (t = 2.29), and the effect of EF on academic achievement as -0.378 (t = 6.39) were significant (P < 0.050), however the effect of FMS on academic achievement as -0.022 (t = 0.34) was not significant (P > 0.050). Accordingly, with the increase in GMS, EF also improved and academic achievement also increased among students. In addition, with the improvement of FMS, students' EF increased, but did not have a direct and significant effect on their academic achievement. The findings in table 3 suggested that the indirect effects of GMS on EF-mediated academic achievement was -0.147 (t = 4.71) and the effect of FMS on EF-mediated academic achievement was equal to 0.065 (t = 1.99); both paths were indirect and significant (P < 0.050). It should be noted that the negative relationship between EF and other variables is due to the inverse scoring in the BRIEF questionnaire, which in fact, low scores in the questionnaire indicate high EF scores.

Based on the results, the value of t in both paths was more than 1.96. Therefore, it can be stated that EF had a partial mediating role on the relationship between GMS and academic achievement and a complete mediating role on the relationship between FMS and academic achievement.

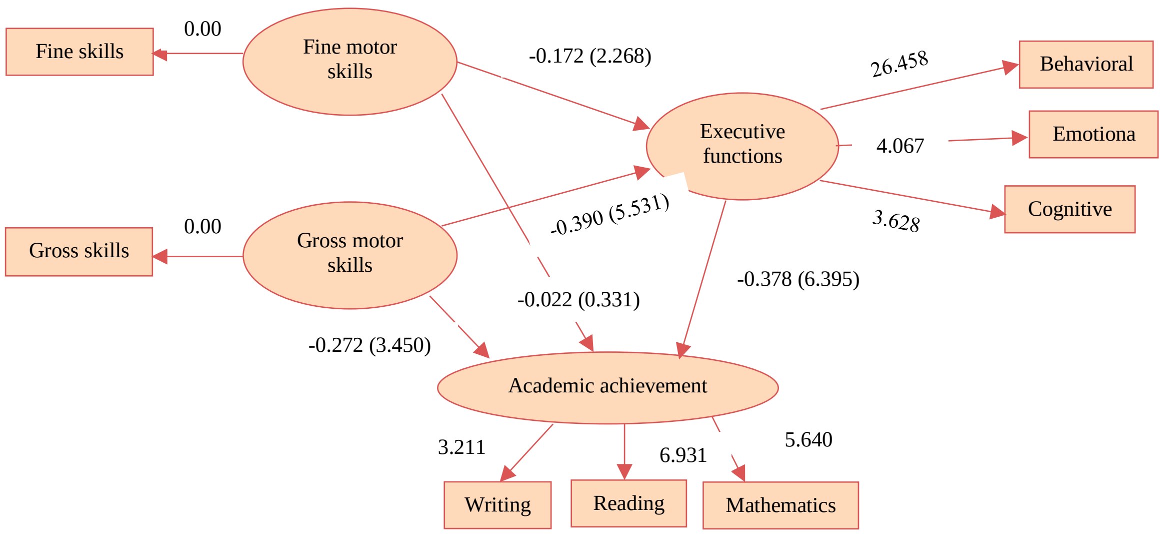

Figure 1. Effect model of gross motor skills (GMS) and fine motor skill (FMS) on academic achievement mediated by executive functions (EF)

Table 3. Direct and indirect effects of the study variables

Effects	Independent variable	Path	Dependent variable	Standard coefficient	Mean	SD	t statistic	P
Direct	GMS	⟵	Academic achievement	0.272	0.268	0.079	3.42	0.001***
	GMS	⟵	EF	-0.390	-0.390	0.068	5.75	0.001***
	FMS	⟵	Academic achievement	-0.022	-0.019	0.066	0.34	0.735
	FMS	⟵	EF	-0.172	-0.174	0.075	2.29	0.023*
	EF	⟵	Academic achievement	-0.378	-0.392	0.059	6.39	0.001***
Indirect with EF mediation	GMS	⟵	Academic achievement	0.147	0.152	0.031	4.71	0.001***
	FMS	⟵		0.065	0.069	0.033	1.99	0.048*

SD: Standard deviation; GMS: Gross motor skills; FMS: Fine motor skill; EF: Executive functions; AVE: Average variance extracted

Accordingly, with the increase in GMS, the academic achievement of students with LD increased. Moreover, with the addition of EF in this relationship, the effect of GMS on academic achievement increased, however FMS did not have a direct and significant effect on students' academic achievement, and increasing these skills increased EF, and with increasing EF, students' academic achievement improved.

Discussion

The aim of this study was to investigate the mediating role of EF in the relationship between FMS and GMS with academic achievement in children with LD. The findings revealed that there was a direct and significant relationship between GMS and academic achievement and these results were consistent with the findings of previous studies which showed that if GMS grows well, it can facilitate children's cognitive function (30,31). To explain the significance of the direct relationship between GMS and academic achievement, it can be said that this is due to the developmental stages of motor skills in the individual; Because, according to the motor development theory, GMS growth occurs earlier than FMS (32). Thus, when GMS reaches a high level of proficiency, it has a greater impact on factors such as academic achievement; Because from the point of view of dynamic systems, gaining proficiency in GMS makes it easier for the child to make the desired movement; This is because more nerves are involved in the activity, and this is due to reaching the third stage of learning, which is the exploitation of degrees of freedom (33). However, when proficiency of movement is not sufficient; That is, the degree of freedom has not developed completely and the child has to hold parts of his/her body stable in order to move (34). As a result, the effect of motor skills that activate higher degrees of freedom (GMS) will be greater than the movements in which lower degrees of freedom are active (FMS) (35).

Given the outcomes of the present study, the relationship between FMS and academic achievement was not direct, but improved the academic achievement in children through the direct effect of FMS on EF. The findings of the study by Kim et al. demonstrated that FMS does affect academic performance, not directly, rather through cognitive abilities (36), which was consistent with the results of the present study. Besides, the results showed that FMS may not directly contribute to math skills, but it does so indirectly through other complex skills such as visual-motor integration. In other words, after controlling attention and visual-motor integration, FMS had no significant relationship with academic achievement (37).

Overall, on the basis of previous studies, although FMS is important for early academic achievement through interaction with the environment (38), achieving proficiency beyond a certain level of FMS may not directly contribute to academic success, but in contrast, FMS may be a prerequisite for other higher-level cognitive processes, such as EF, that are more important for academic achievement (36).

Explaining the significant relationship between motor skills and EF, it can be stated that these two variables are not separate from each other, but relate to each other and other skills and provide the basis for successful behaviors in children's learning (39). Due to these connections, motor skills may be related to success in various paths. Strong motor skills may also compensate for poor behavioral or academic skills (11). The correlation between motor skills and EF has been reported to be positive in normal students (16). Thus, although motor skills and EF are distinct, there is a significant relationship between them (15). This relationship may be greater for academic achievement, especially in children with LD who have severe motor skills and EF problems.

The results of the present study on the existence of a significant and positive correlation between EF and academic performance in children with LD, consistent with previous studies (40) have shown that children with LD, compared to their normal counterparts, often perform weaker in different areas of EF. For example, problems in academic performance of children with LD were related to problems with WM, which is part of their EF (41). Inability to pay attention to homework, which is another part of EF, is another problem for people with LD. Attention is essential for cognitive function, memory, and learning behavior; So that even minor deficiencies in attention can impair learning (42). Furthermore, planning and problem solving, which is another important part of EF and have the ability to formulate actions in advance and approach a task in an organized, strategic, and efficient manner (43), is an essential ability for academic skills (7). In addition, children with attention, self-control, and WM may be more comfortable engaging in new tasks that require complex motor skills (11). Therefore, improving EF can facilitate academic achievement (44).

Regarding the indirect relationship between motor skills and academic achievement, the results of the present study were similar to the findings of the study Chang et al. (45). Moreover, the present study develops the results of recent studies indicating the indirect role of motor skills on academic achievement through the mediation of cognitive processes, for children with LD (46).

Some findings support the mediating patterns in which the relationship between FMS and GMS and academic achievement is reflected by EF, and previous mediating models that indirectly link the motor skills to academic achievement. For example, it was consistent with the study of Rigoli et al., who reported the positive effect of motor coordination on academic achievement through cognitive mediation (47).

The results of the present study contradicted the findings of the study by Aadland et al. (48). These results showed that there was no indirect relationship between basic motor skills and academic performance (48). The reason for the discrepancy between these two studies can be attributed to the type of test and its separation; Because in the present study, GMS and FMS were discussed as two separate variables. However, a significant and direct relationship was found between GMS and academic achievement.

The fact that the prediction of the cross-section of constructs was achieved more than the strong stability within the construct supports the notion that these processes do not develop separately, but are in fact interdependent (49). Therefore, the development and integration of these skills is essential for the successful completion of classroom assignments and academic achievement (11).

Research has shown that specific motor interventions can help children, so that in addition to improving motor skills, improve their cognitive abilities (7,50). For example, a study suggested that a four-month ball skill intervention in children with LD was an effective way to improve problem solving in addition to improving ball skill performance (7). Additionally, based on the results of a study, it was found that a six-month football training program in children improved EF in addition to improving their coordination skills (50). Therefore, the quality and quantity of interventions are very important to support the motor skills and cognitive abilities of children with LD. Overall, the results of the present study emphasize the belief that the child's movement is a vital factor for academic performance and teachers should pay enough attention to it (3).

Limitations

Controlling the concurrent effect of some other variables that may have occurred during the study, differences in children's motivation levels, and the effect of fatigue on their performance were among the limitations of the study.

Recommendations

Future investigations could compare the mediating role of cognitive and psychological factors and show which ones are a priority for the relationship between motor skills and academic achievement in children with LD. It is also suggested that the role of GMS and FMS training interventions as well as EF exercises be investigated in future studies.

Conclusion

Overall, the fundamental importance of motor skills in the academic achievement of children with LD can be emphasized. In addition, the present study emphasizes the importance of EF for the academic achievement of children with LD, which in addition to the strong direct effect, contributes to the indirect effect of motor skills on children's academic achievement.

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Authors' Contribution

Rasool Ebrahim-Najafabadi: study design and ideation, attracting financial resources for the study, study support, executive, and scientific services, providing study equipment and samples, data collection, analysis and interpretation of results, specialized statistics services, manuscript preparation, specialized manuscript evaluation in terms of scientific concepts, approval of the final manuscript to be submitted to the journal office, responsibility for maintaining the integrity of the study process from the beginning to publication, and responding to the referees' comments; Rokhsareh Badami: study design and ideation, study support, executive, and scientific services, providing study equipment and samples, analysis and interpretation of results, specialized statistics services, manuscript preparation, specialized manuscript evaluation in terms of scientific concepts, approval of the final manuscript to be submitted to the journal office, responsibility for maintaining the integrity of the study process from the beginning to publication, and responding to the referees' comments; Zohreh Meshkati: study support, executive, and scientific services, manuscript preparation, specialized manuscript evaluation in terms of scientific concepts, approval of the final manuscript to be submitted to the journal office, responsibility for maintaining the integrity of the study process from the beginning to publication, and responding to the referees' comments; Sara Aghababaei: study support, executive, and scientific services, manuscript preparation, specialized manuscript evaluation in terms of scientific concepts, approval of the final manuscript to be submitted to the journal office, responsibility for maintaining the integrity of the study process from the beginning to publication, and responding to the referees' comments.

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Conflict of Interest

The authors have no conflict of interest.

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