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Research Paper: The Relationship Between Bimanual Coordination and Writing Skill in Elementary School Children With Developmental Coordination Disorder

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ABSTRACT

Introduction: This study investigated the relationship between bimanual coordination and writing skill in the elementary school children with developmental coordination disorder (DCD) living in Urmia City, Iran.

Material and Methods: A total of 60 elementary school children, both male and female, with DCD aged 7 to 9 years old were selected based on the Movement Assessment Battery for Children (MABC) test and relevant questionnaires. These subjects were requested to perform in-phase and anti-phase patterns. Writing composition scores and bimanual coordination tool were used as measures of children's writing performance and bimanual accuracy. Descriptive statistics and coefficient regression were used for data analysis.

Results: The results indicated a statistically positive correlation between children's bimanual accuracy and their writing skill. In other words, regression indicated that bimanual coordination accuracy test was a significant predictor for the writing skill (R^2=0.331, P=0.001).

Conclusion: In general, motor control ability of children with developmental coordination disorder and its relationship with writing performance should be considered.

1. Introduction

Writing is an active and productive language skill essential for academic success. However, writing is not an easy skill to be mastered. According to Kroll [1], teachers need to understand the complex nature of writing as an intellectual activity, and consequently choose a suitable teaching method that takes into account such nature. In writing, the writer cannot receive immediate feedback, so he/she has to imagine the readers' reactions that are affected by their life chances, family income, well-being, parents' educational level, previous school suc-

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cess, cultural activities, parent-child relations, teacher/school/pupil interactions, and parent-school relationships [2]. Although there is a wealth of research on the correlations between social variables and academic performances [2], mechanisms related to motor ability and cognitive performances are still unclear. The present study aimed to bridge this gap.

Cox et al. [3] studied the effect of tactile perception on upper limb motor function in children with developmental coordination disorder (DCD). They reported that spatial tactile perception predicts handwriting legibility and speed of functional tasks. Based on their results, tactile function, especially single point localization, should be the primary tactile assessment used to detect etiology of upper limb motor difficulties experienced by children with DCD. However, in Cox et al. [3] investigation, the tasks that involve only proprioception and use of other senses are neglected. Proprioceptive sensory input from the muscle spindles and tendons is crucial for movement control. It allows the central nervous system to monitor the position and speed of the moving limbs and adjust the motor command if necessary. Besides proprioception, vision is also an important source of feedback which is essential for maintaining the required coordination patterns during bimanual movements [4].

Vision is considered as the most important perceptive modality in interaction with environment in daily life. Moreover, vision is superior to other senses for perceiving spatial information [5]. Furthermore perhaps audition could also be taken as a sensory input influencing the coupling of the limbs during bimanual coordination as the sounds produced by the motion may provide feedback. In fact, the link between the auditory and the motor systems has been examined in a recent study during performance of bimanual linear coordination task with a sliding device [5, 6]. In performing bimanual coordination task, all senses are involved, and to perform in-phase and anti-phase patterns besides vision [7], spatial tactile perception (proprioception) [3], and all three effective senses should be used.

Having the cognitive and motor features simultaneously, it is a good idea to compare the academic performance aspect of the writing skill with its motor performance. A lot of factors related to motor performance play significant roles in learners' performance. Motor performance has strong association with the academic performance in elementary school age [8], however in some studies the adults were used as subjects [9].

To the best of our knowledge, no research has been ever done on the association between bimanual coordination and writing performance. To make bimanual coordination movements in a horizontal plane, the principles of coordination are realized in two stable patterns: in-phase (0° relative phase) and anti-phase (180° relative phase). The in-phase coordination mode refers to simultaneous mirror-symmetrical movements towards and away from the body midline. It involves concurrent activation of homologous muscle groups [10-14]. The anti-phase coordination mode refers to movements made, simultaneously, in the same direction from one side of body midline to its other side; resulting in performance of parallel (isodirectional) movement pattern in extrinsic space [11, 15-17].

With increasing movement frequency, in-phase coordination remains stable while anti-phase coordination destabilizes, and if unopposed, eventually results in spontaneous transition to the in-phase movement pattern [12, 18, 19]. In this study, the movements requiring sequential and simultaneous use of both sides of the body have been examined. Most studies in motor performance tests used the combination of movements, such as balance and Bruininks-Oseretsky test [20], however there is no particular research examined the relationship between bimanual coordination and academic performance. Although this study goes one step further and studies bimanual coordination in the component areas including in- and anti-phase patterns.

In the present study, we used a bimanual coordination task that consisted of flexion and extension movements with both wrists in either in-phase or anti-phase mode. The continuous nature of the bimanual actions in the present study requires participants to control their limbs extensively and continuously, through visual and proprioception or audition feedback loops. Our primary goal was to assess the relationship between academic writing performance and each bimanual coordination as the strength of coupling between two wrists. It is also of our interest to allow further insight into the dynamics of bimanual coordination with writing in elementary school children with DCD. Evidently, there is a close relationship between motor and cognitive development. Much evidence for this relationship derives from children's developmental disorders such as attention deficiency, hyperactivity disorder, and autism spectrum disorder that impair motor function [21, 22].

Exploring the relationship between coordinative behavior and academic performance in children with DCD received less attention. However, to our knowledge, the

technique of assessment of motor performance in some studies used visual perception tests [7], whereas bimanual tasks have received much less attention. On the other hand, in most studies reading and math have been used as the measure of the academic performance, but the writing performance as an effective variable has been neglected [9]. The present experimental design also addressed the question whether in-phase and anti-phase bimanual coordination patterns have any relationship with writing ability in elementary school children with DCD.

2. Materials and Methods

Participants

The study participants were chosen based on purposeful sampling method and the Movement Assessment Battery for Children (MABC) test and relevant questionnaire. In this way, a total of 60 elementary school children (both females and males aged between 7 and 9 years) with DCD in Urmia City, Iran were selected. All children were right handed (assessed by the Edinburgh Handedness Inventory; Oldfield, 1971) [23] and Persian speaking students learning Persian as a language. Inclusion criteria were having normal vision based on the Snellen chart test and self-reported normal audition. The children were novices to the bimanual coordination task and unaware of the study purpose. The parents provided written informed consent form, which has been approved by the local Ethics Committee (Urmia University) before the start of the study.

Apparatus and equipment

Writing composition

To measure the ability of students in writing, the researcher asked the participants to write a composition about "why they study Persian language." In order to rate the students' papers and quantify their writing performance, the researcher consulted some lecturers on how to grade the papers logically. Finally, the composition papers were evaluated based on criteria established by Jacobs, Zinkgraf, Wormuth, Hartfield, and Hughey [24]. According to the criteria, the compositions were graded based on 5 aspects of content, organization, vocabulary, mechanics, and language use. The maximum scores for each aspect were as follows: content=4, organization=4, vocabulary=6, language use=8, and mechanics=3. The total maximum grade was 25. The required time to write this composition was 25 minutes.

Bimanual coordination apparatus

Participants sat on an adjustable chair at a table covered by a white laminated poster board (50 cm deep and 86 cm wide). Wrist movements were permitted in only the extension and flexion orientation from midline. Attached in parallel to the slides were linear potentiometers (Bourns Instruments, Riverside, CA), which encoded the displacement of the handled over a 20-s trial. An auditory metronome (NCH Swift Sound Tone Generator, version 2.01) provided pacing information for bimanual task [6].

Procedures

The composition was written during a single session class time lasting approximately 30 minutes. The researcher was first coordinated with the school authorization to distribute the questionnaires. Then, the researcher explained the procedure to the students and also obtained information about the characteristics of the study population. Students were given 25 minutes to write a composition on a given topic. The compositions were graded to indicate students' general writing skill. The obtained data were then coded and results were entered into SPSS for statistical analysis. All scores were

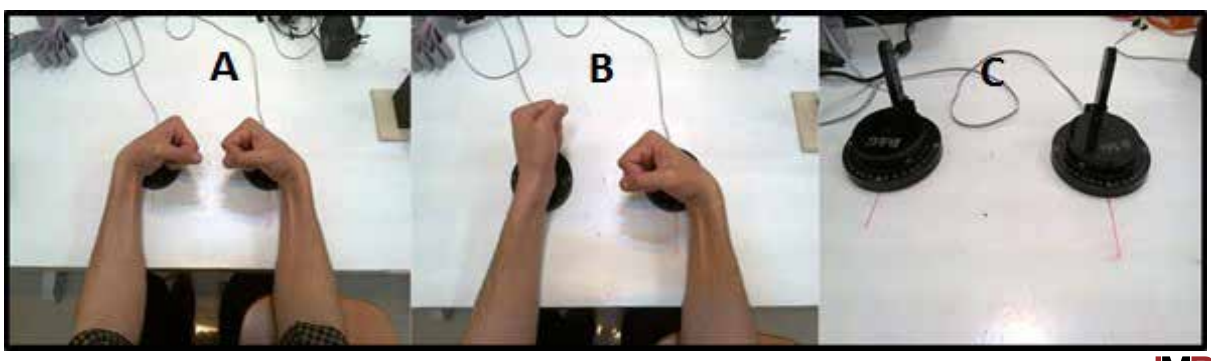

Figure 1. The bimanual wrist coordination task: (A) In-phase pattern, (B) Anti-phase pattern, and (C) Bimanual coordination apparatus

then calculated for each subcomponent and component as well as for the total number of answers in the questionnaire. For the sake of anonymity and confidentiality, the students' identities were removed from the questionnaires. To conduct the writing test, the research instruments were administered during one class session. After that, the parents provided written informed consent form, which has been approved by the local Ethics Committee (Urmia University). Next, the participants were asked to complete a health questionnaire prior to their inclusion in the study. The participants were 60 children with DCD. All were right handed (assessed by the Edinburgh Handedness Inventory; Oldfield, 1971) [23], aged between 7 and 9 years with a mean age of 8.1 years. Inclusion criteria were having normal vision (based on the Snellen chart test) and self-reported normal audition.

Next, the participants were introduced to the task, which required them to hold two handles attached to the moving slides and reposition them horizontally in the left-right direction (wrist extension and flexion). While holding the two handles, the participants yielded 0° relative phase (in-phase) and 180° relative phase (anti-phase) patterns. They were instructed to coordinate with a metronome by performing a complete cycle of in-out-in handle displacement with each beat. The metronome paced the required speed or frequency of limb movement beginning at a slow speed with a frequency of 58 beat/minute for 20 seconds. After completion of the 20-second trial at slow speed, the same required coordination task was paced at a medium speed (90 beat/minute), and subsequently at a fast frequency (152 beat/minute). When the participants entered the laboratory, we obtained their consent (and assent, when appropriate).

The participants sat on an adjustable chair at a table covered by a white laminated poster board (50 cm deep and 86 cm wide). Wrist movements were permitted in only the extension and flexion orientation from midline (Figure 1). Attached in parallel to the slides were linear potentiometers (Bourns Instruments, Riverside, bCA), which encoded the displacement of the handled over a 20-s trial. Data were sampled using a microprocessor (80486) with a sampling rate of 150 Hz (i.e., one sample each 5 ms). Lab Windows software (National Instrument Corporation, version 2.2.1) initiated and terminated 20-s trials and also provided data capture and recording of limb position over time.

Experimental design and data reduction

The position signals were smoothed with a symmetrical Bartlett (triangular) filter. Its time series was derived from the position signal using a 2-point central difference algorithm and then smoothed with a Bartlett window. The smoothed position and velocity time series were then used to calculate each component of the near-continuous phase state for each trial according to the formula:

$$\phi R=tan\text{-}1\{(dXR/dt)/XR\}$$

Where ϕR is the phase of the right wrist at each sample, XR is the position of the right wrist rescaled to the interval, {-1,1} for each cycle of oscillation and (dXR/dt) is its normalized instantaneous velocity. The same formula was used to calculate from the position and velocity signals of the left wrist. The relative phase (φ) between the two wrists, was then expressed as:

$$\varphi=\phi R-\phi L$$

Descriptive and inferential statistics were performed for data analysis. To examine the relationship between the bimanual coordination of both in-phase and anti-phase and the writing ability, correlation coefficient and coefficient regression test was used. The level of significance was set at 0.05.

3. Results

The researchers dealt with demographic features of the participants and the tables of frequency distributions and percentage were prepared. Descriptive statistics such as means, standard deviations, frequencies, and percentages were computed. Then, the tables of descriptive statistics were used in order to describe the variables of the study (bimanual coordination and writing performance) (Figure 3). To analyze the data and test the study hypothesis, coefficient regression test was used and collected data were statistically treated through SPSS 16.

Based on Figure 2, the writing composition has the mean value of 16.84 with standard deviation of 2.918. In order to rate the students' composition and quantify their writing performance, the researcher consulted some ex-

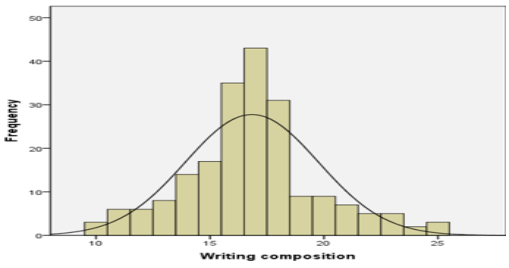

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Figure 2. The distribution variable of writing composition

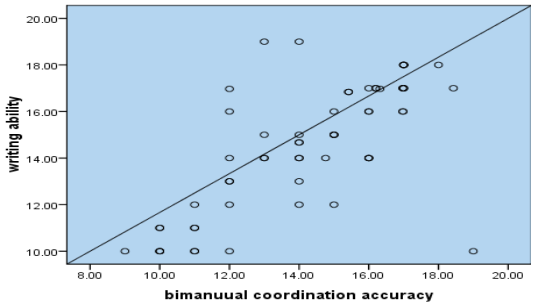

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Figure 3. The relationship between writing ability and bimanual coordination accuracy

perts and used the criteria established by Jacobs et al. (1981) [24]. The criteria comprise content (maximum score 4), organization (maximum score 4), vocabulary (maximum score 6), language use (maximum score 8), and mechanics (maximum score 3). The maximum total mark was 25 points. The needed time to write this composition was 25 minutes. The researcher corrected the papers and scored them. Students whose scores fell below the mean were classified as children with low performance in writing and children whose scores fell above the mean were classified as children with high performance in writing.

There is a significant relationship between children's "bimanual coordination" and "writing composition" based on the R^2 (0.331) at the significance level=0.001. According to coefficient regression, there is a significant relationship between "students' writing composition" and "bimanual coordination accuracy" ($P<0.01$) (Table 1). In other words, regression indicates that motor coordination test is a significant predictor for the writing performance.

4. Discussion

The experiment was designed to investigate the relationship between bimanual coordination movement and writing skill. Elementary school children in Urmia City, Iran with DCD participated in the study. The subjects performed coordination tasks. They were required to produce in-phase or anti-phase movements with their wrists where visual, proprioceptive, and audition feedback are available. Results indicated that in-phase or anti-phase movements were more important in prediction of writing skill. Overall, these finding reveal that when the children with DCD perform both the in-phase and anti-phase coordination tasks with higher mean relative phase error scores and poorer coordination consistency they will likely to have weak academic performance.

The findings of the study indirectly indicate that most children with higher bimanual coordination might have experienced learning in writing ability. Support was found for the significant relationship between children' motor performance and writing skill. It shows that children with low motor function score have lower scores in writing test. This was consistent with some previous studies reported that academic performance would affect students' motor function [9, 24-26]. However, extracurricular activities, like bimanual coordination movement are necessary to help weak students because more opportunities for interaction may lead to an increase in productive academic achievements. A noteworthy result of writing composition was that although many school students were interested in writing, they lacked the necessary competence which was the result of poor motor function.

Overall, the present findings support the results of Piek et al., who also found a strong relationship between gross motor function and cognitive ability. The results are also in agreement with those studies that reported a positive and significant relationship between interlimb coordination and academic performance [27, 28]. In addition, our study results are consistent with Prunty et al. study results [29] that evaluated 28 children with developmental coordination disorder. In their research, they studied the impact of handwriting difficulties on compositional quality of children with DCD. These children performed significantly below their typically developing peers on five of the six Wechsler objective language dimensions items. They also had a higher percentage of misspelled words.

As a general observation, these findings indicate that gross motor ability during childhood is a predictor of school-age academic performance. The present results support those findings and show that gross motor tasks that involve in particular interlimb coordination, provide insight into the behavioral association. Regarding a possible explanation for the significant association found in this study, as noted in the introduction, the use of all

Table 1. Coefficient regression between bimanual coordination and writing performance

Variables	R^2	β	t	Sig.
In-phase and anti-phase patterns of bimanual coordination	0.331	0.456	5.564	0.001

Dependent variable: writing composition

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senses in bimanual coordination and interlimb coordination primarily involves movements requiring sequential and simultaneous use of both sides of the body. However, these actions involve the timing of locomotor cycles of the limbs in relation to one another. That general idea supports the notion of parallel processing [30] for motor and cognitive functions suggesting that coordination exercises facilitates neuronal networks that result in a pre-activation of cortical activit{ies responsible for cognitive functions such as attention [30, 31].

To the best of our knowledge, this is the first study that thoroughly examined the association between bimanual coordination and writing skill in elementary school children with DCD. However, there are some limitations and future directions that should be mentioned in the present research: First, apparently there was a ceiling effect on some outcome measures for children with DCD, including the stereotype one. Further research is required to extend the difficulty of these tests and determine the level at which children be challenged with these skills in functional tasks. Second, a larger sample size may lead to significant outcomes in writing skill of elementary school children with DCD.

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Conflict of Interest

The authors declared no conflicts of interest.

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