Peer-reviewed and Open access journal
ISSN: 1804-1191 | www.pieb.cz

ATI - Applied Technologies and Innovations
Volume 3 | Issue 3 | November 2010 | pp. 30-39

The pursuit flexibility of children with attention-deficit/hyperactive disorder

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This research explores the kinematics performance of children with ADHD on the Pursuit Test at four speeds (i.e., 30, 50, 80, 100 millimeters per second) to assess their movement flexibility and its quality. The study consists of 23 children with ADHD and 38 normal children. The results have shown that children with ADHD demonstrate a faster speed in movement, along with greater acceleration, and the entire movement process tends to be less smooth. Children with ADHD also demonstrated greater difficulty in motor control while the speeds of pursuit test increased. Discussion regarding children with ADHD had difficulty in implementing close-loop movements, higher-level cognitive processing, and higher-speed activities were proposed. Clinical implications, study limitations and suggestions for future study were provided.

Keywords: ADHD, fine motor performance, motor flexibility, Pursuit Test.

Introduction

Attention-deficit/hyperactivity disorder (ADHD) is a persistent, prevalent, heterogeneous, and heritable neurodevelopmental disorder that affects 3-10% of school aged children (Barkley, 1998). It is characterized by early onset patterns of hyperactivity, inattentiveness and impulsiveness in childhood. Three subtypes are identified in the diagnostic and statistical manual of mental disorders (DSM-IV) classification system: a predominantly inattentive, a predominantly hyperactive-impulsive and a combined subtype (American Psychiatric Association, 1994).

Significant difficulty in motor-related capabilities has been extensively researched and documented in research literature. The wide range of motor-related difficulties includes delayed development of motor milestones, motor coordination, and movement execution (Fliers, Rommelse, Vermeulen et al., 2008; Hurk, Adam, Hendriksen et al., 2005; Meyer and Sagvolden, 2006). Specifically, problems with motor preparation and decision process (van der Meere, van Baal, and Sergeant, 1989; van der Meere, Vreeling, and Sergeant, 1992), movement programming (Periera, Eliasson, and Forssberg, 2000; Pereira, Landgren, Gillberg, and Forssberg, 2001; Eliasson, Rosblad, and Forssberg, 2004), reaction time and movement speed (Robins, 1992; Reader, Harris, Schuerholz, and Denckla, 1994; Steger et al., 2001), motor overflow (Mostofsky, Newschaffer, and Denckla, 2003), graphomotor output (Marcotte and Stern, 1997; Schoemaker, Ketelaar, Zonneveld, Minderaa, and Mulder, 2005), gross motor skills (Harvey and Reid, 1997), fine motor skills and manual dexterity (Piek et al, 1999; Tseng, Henderson, Chow, and Yao, 2004; Whitmont and Clark, 1996) have been documented in previous studies of children with ADHD. The majority of motor-related studies emphasized on discussions regarding

[1] This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors. We thank the families who participate in this research.

these children and their performances on neuromotor tasks or measures (Ben-Pazi, Gross-Tsur, Bergman, and Shalev, 2003; Brandeis et al., 2001; Eliasson, Rosblad, and Forssberg, 2004; Jucaite, Fernell, Forssberg, and Hadders-Algra, 2003; Karatekin, Markiewicz, and Siegel, 2003; Kooistra et al., 2005; Mostofsky, Newschaffer, and Denckla, 2003; Piek, Pitcher, and Hay, 1999; 2003; Schoemaker, Ketelaars, Zonneveld, Minderaa, and Mulder, 2005; Slaats-Willemse, Sonneville, Swaab-Barneveld, and Buitelaar, 2005; Tiffin-Richards et al., 2004; Tseng, Henderson, Chow, and Yao, 2004.

However, many of the movement measurement tools determine whether flaws exist in movements based on whether individual is capable of carrying out specific movements without knowing the course of the movement. Thus, a child may complete certain specified movements but with poor movement quality, while the results of the assessment remains normal. Nevertheless, whether the performance of children with ADHD might be affected by the presentation of stimulus or tasks at various speeds also remain unclear.

In 2004, Eliasson incorporated computer programs and asked the participants, by using the mouse on the testing facilities positioned on the surface of the table, to look at the starting and end points on the monitor and try link the two points together. This investigation detects whether problems exist in children with ADHD during the performance of visual feedback removal (to remove the path from the screen), and if precise actions were taken to accurately reaching the end point. The results showed that children with ADHD displayed problems in movement accuracy and require longer time to complete the action. Additionally, poor control was also presented in action planning and action speed (Eliasson et al., 2004). Slaats-Willemse (2005) asked the participants to control the mouse cursor, allowing the cursor to follow and move along the path displayed on the monitor, while the directions of the trajectory are to be altered randomly. This is to measure the distance and trajectory of its deviation, as well as the difference between the cursor and standard trajectories when sudden change in direction occurs. The results of this study found that ADHD group performed worse than the control group in movement flexibility (Slaats-Willemse et al., 2005). Schoemaker (2005) measured the children with ADHD display their ability of using a pen to draw lines as they appear on the computer monitor. The study discovered that children with ADHD draw slower but more fluent, require less break time, and apply more hand strength. Furthermore, instead of staying on the lines, they tend to deviate away by drawing above or below the lines (Schoemaker et al., 2005).

In the research field of human kinesiology, motion analysis system commonly captures the kinematics data, such as velocity, acceleration, or jerk, to analyze individual's motor capability and to represent the movement process and its quality. The aim of this study is to assess the movement flexibility and quality of children with ADHD through their kinematic performance on pursuit test at various speeds.

Method

Participants

A total of 61 children (23 children classified as having symptoms of ADHD and 38 matched controls; 46 boys and 15 girls; aged from 6 years to 11 years) participated in the study. The children were diagnosed as ADHD by the child psychiatrist based on the criteria of the DSM-IV (American Psychiatric Association, 1994). Participants taking psychological medications were omit medication for 24 hours prior to the participation in the study. The age-and IQ-matched comparisons were recruited from elementary schools in the neighborhood. According to the information reported by parents, children with any history of neurological, psychological, and physiological problems or behavioral and movement difficulties that might interfere with their daily performance were also excluded.

Measures and variables

Prescreen measures included the Peabody Picture Vocabulary Test-Revised (PPVT-R; Dunn and Dunn, 1981) and the Beery-Buktenica Development Test of Visual-Motor Integration (VMI-4th ed., Beery 1997). The Peabody Picture Vocabulary Test - Revised (PPVT-R) was a measure of receptive language for individuals aged from 2.5 to 40 years. The PPVT-R allows a verbal or nonverbal response; it is individually administered and untimed (although administration time typically requires only 15-20 minutes). The PPVT-R has acceptable psychometric characteristics to be used as a measure of cognitive ability. In present study, only children scored 85 or higher on PPVT-R were included to ensure the adaptive cognitive functioning on following instructions and understanding the study procedures. VMI is a norm-referenced standardized test which is designed to measure visual-motor integration in individuals from age 3- to 18-year-old. The participant was asked to copy 27 geometric forms, arranged in developmental sequence, from less to more complex, in the Test Booklet. In present study, VMI was administered to exclude the children with visual motor integration problems that might affect their performance on pursuit movement.

Pursuit Test is mainly used to measure a child's motor flexibility, which is defined as a child's need to have precise plans and the ability to implement the unforeseeable mobility. During the tests, participants were seat on an adjustable chair with foot plates firmly supported at a table and were asked to use the stylus on the tabletop touch-sensor monitor to move the plus sign as fast as possible along the trajectory of the asterisk symbols on the touch screen tailing the target. The moving speeds of the plus sign are to be set at 30, 50, 80, 100 millimeters per second, respectively. The test results can capture the participant's movement velocity, acceleration, jerk, the displacement of the path, the path in which the stylus has taken, as well as other standard deviation values. The definition of each variable is described as follows (Huijbregts et.al., 2003; Slaats-Willemse et al., 2005):

Number of Inversions in Velocity, also referred to as the NIV: The measurement of the course of movement in terms of velocity and time coordinates. The number of inversions in velocity was used to calculate the degree of movement automation, where greater inversion values signify the lesser smoothness of movement process (Meulenbroek and Van Galen, 1988; Tucha and Lange, 2001).

Number of Inversions in Acceleration (NIA): The measurement of the course of movement in terms of acceleration and time coordinates. The number of accelerated inversions was used to calculate the degree of movement automation, and that greater accelerated inversion values means the lesser smoothness of the movement process (Meulenbroek and Van Galen, 1988; Tucha et al., 2001).

Velocity: The value of location changes within each unit of time. The greater the value of speed means greater force is used during the implementation of movements (Hamilton and Luttgen, 2002). In addition to measuring the average value and the standard deviation of velocity, the movement elasticity tests measure the individual's average differential velocity between the movement speed and the baseline values (the movement speed of the asterisks).

Acceleration: The variation of speed per unit of time. The greater the acceleration values, the greater the implementation of the force used by the individual during the movements (Hamilton and Luttgen, 2002).

Jerk: The variation in acceleration per unit of time, which means using the differential acceleration value of movements to represent the degree of smoothness in the process. The larger the value of jerk signifies the lesser the smoothness of movement (Zatsiorsky, 1998). The standardized value of jerk is the standardization of an individual's completion time and the values of the distance displacements, thus it can be used to represent the degree of smoothness in movement.

Procedures

The study was reviewed and approved by National Cheng Kung University Institute Review Board. The parents and children were received a detailed explanation of the study and its procedure and the parents provided written informed consent for participation prior to their children's initial prescreening. Children were seat on an adjustable chair with foot plates firmly supported at a table. During the administration of the test, a touch screen monitor was positioned flatly on the desktop, and the participants were asked to use their natural and habitual postures while performing the Pursuit test. Testing was conducted in two sessions with a 10-min recess in between. The prescreening PPVT-R and VMI tests were administered in the first session, followed by the pursuit flexibility test in the second session. The compensatory gifts were then provided as the reinforcement for enhancing children's motivation and participation.

Statistical analysis

All statistics were performed with SPSS-Windows version 12.0. All analyses of the dependent variables were two-tailed and the p-value of < 0.05 was set to indicate statistical significance. Trend level of significance with $p<0.01$ was also showed. Independent sample t tests were computed to analyze for the differences between groups.

Results

Table 1 presents participants' performance on prescreening tests. Two groups do not significantly differ on age and the scores of prescreening tests.

TABLE 1.THE CHARACTERISTICS OF PARTICIPANTS

	ADHD (N=23) Mean (SD)	Normal (N=38) Mean (SD)	*t*	*p*
AGE (Month)	111.65 (22.81)	111.47 (19.90)	.032	.974
PPVT-R standard score	117.61 (15.22)	115.76 (11.85)	.527	.600
VMI score	107.87 (11.42)	112.89 (10.32)	-.1759	.084

Note: **p* <.05, **p* <.01. ADHD - Attention-deficit Hyperactivity Disorder, PPVT-R - Peabody Picture Vocabulary Test-Revised, VMI - Beery-Buktenica Development Test of Visual-Motor Integration.

TABLE 2. KINEMATICS PERFORMANCE OF ADHD AND NORMAL GROUP ON PURSUIT TEST (V=30 MM/S)

	ADHD (N=23) Mean (SD)	Normal (N=38) Mean (SD)	*t*	*p*
Number of inversions in velocity	347.65 (23.75)	343.44 (4.46)	.768	.448
Number of inversions in acceleration	418.22 (19.23)	415.85 (15.83)	.522	.604
Maximum velocity (mm/s)	160.41 (58.95)	132.78 (24.66)	2.137	.042*
Mean of velocity (mm/s)	36.55 (1.49)	35.37 (0.87)	3.456	.002**
Standard deviation of velocity(mm/s)	14.75 (3.07)	13.15 (2.17)	2.180	.036*
Mean of velocity difference(mm/s)	15.49 (2.75)	13.97 (2.15)	2.404	.019*
Maximum acceleration (mm/s2)	1359.98 (720.41)	1064.47 (250.08)	1.899	.069
Maximum decelerations (mm/s2)	1267.13 (772.06)	999.60 (278.52)	1.600	.122
Maximum jerk (mm/s3)	26032.61 (14996.92)	21216.00 (5809.22)	1.475	.152
Mean of jerk (mm/s3)	3454.13 (815.26)	3190.61 (544.96)	1.514	.135
Standard deviation of jerk (mm/s3)	2080.87 (684.81)	1828.55 (348.03)	1.643	.111
Standardized jerk (mm/s3)	289194.46 (83276.87)	262493.43(44358.61)	1.421	.166

Note: * *p* <.05, ** *p* <.01. ADHD - Attention-deficit Hyperactivity Disorder.

TABLE 3. KINEMATICS PERFORMANCE OF ADHD AND NORMAL GROUP ON PURSUIT TEST (V=50 MM/S)

	ADHD (N=23) Mean (SD)	Normal (N=38) Mean (SD)	*t*	*p*
Number of inversions in velocity	325.85 (22.65)	318.55 (16.83)	1.438	.56
Number of inversions in acceleration	410.70 (18.09)	406.33 (15.89)	.987	.345
Maximum velocity (mm/s)	276.00 (103.43)	209.97 (34.88)	3.626	.001**
Mean of velocity (mm/s)	60.60 (3.36)	57.96 (1.48)	3.563	.001**
Standard deviation of velocity (mm/s)	23.02 (4.79)	21.11(3.63)	1.644	.084
Mean of velocity difference (mm/s)	24.28 (4.88)	22.14 (3.73)	1.933	.058
Maximum acceleration (mm/s2)	2592.30 (2012.18)	1654.82 (430.30)	2.204	.038*
Maximum decelerations (mm/s2)	2543.48 (1933.93)	1456.12 (357.94)	2.669	.014*
Maximum jerk (mm/s3)	53624.64 (43179.52)	30273.10 (9385.46)	2.557	.018*
Mean of jerk (mm/s3)	5062.32 (1421.88)	4603.16 (735.34)	1.437	.161
Standard deviation of jerk (mm/s3)	3172.97 (1277.28)	2614.17 (418.92)	2.033	.053
Standardized jerk (mm/s3)	272376.73 (110791.62)	253840.56 (154690.08)	0.501	.618

Note: * $p < .05$, ** $p < .01$. ADHD - Attention-deficit Hyperactivity Disorder.

TABLE 4. KINEMATICS PERFORMANCE OF ADHD AND NORMAL GROUP ON PURSUIT TEST (V=80 MM/S)

	ADHD (N=23) Mean (SD)	Normal (N=38) Mean (SD)	t	p
Number of inversions in velocity	307.57 (21.68)	306.07 (16.76)	.303	.763
Number of inversions in acceleration	400.43 (17.93)	396.67 (16.00)	.851	.398
Maximum velocity (mm/s)	358.04 (101.75)	297.72 (51.90)	2.642	.013*
Mean of velocity (mm/s)	98.18 (9.37)	93.01 (3.60)	2.532	.018*
Standard deviation of velocity(mm/s)	36.34 (9.88)	31.43 (5.71)	2.172	.038*
Mean of velocity difference(mm/s)	37.41 (9.75)	32.30 (6.02)	2.535	.014*
Maximum acceleration (mm/s2)	3003.99 (1435.28)	2254.34 (575.09)	2.238	.024*
Maximum decelerations (mm/s2)	2676.01 (1449.09)	1962.38 (628.40)	2.391	.034*
Maximum jerk (mm/s3)	56810.14 (30320.16)	41126.32 (14793.73)	2.319	.028*
Mean of jerk (mm/s3)	6655.80 (1649.20)	6166.05 (1370.49)	1.252	.215
Standard deviation of jerk (mm/s3)	3996.88 (1296.04)	3477.50 (807.21)	1.932	.058
Standardized jerk (mm/s3)	207877.72 (60043.92)	192017.50 (40246.42)	1.236	.221

Note: * p <.05, ** p <.01. ADHD - Attention-deficit Hyperactivity Disorder.

TABLE 5. KINEMATICS PERFORMANCE OF ADHD AND NORMAL GROUP ON PURSUIT TEST (V=100 MM/S)

	ADHD (N=23) Mean (SD)	Normal (N=38) Mean (SD)	t	p
Number of inversions in velocity	308.83 (18.32)	298.43 (14.97)	2.414	.019*
Number of inversions in acceleration	402.57 (15.31)	395.97 (14.34)	1.699	.095
Maximum velocity (mm/s)	463.76 (171.78)	367.29 (83.28)	2.947	.005*
Mean of velocity (mm/s)	123.15 (11.07)	116.95 (6.42)	2.777	.007*
Standard deviation of velocity (mm/s)	44.11 (10.78)	38.90 (6.47)	2.097	.044*
Mean of velocity difference (mm/s)	46.51 (12.70)	40.08 (6.93)	2.237	.033*
Maximum acceleration (mm/s2)	4178.04 (2513.85)	2824.34 (1387.17)	2.373	.024*
Maximum decelerations (mm/s2)	3985.65 (2791.38)	2490.00 (1593.35)	2.349	.025*
Maximum jerk (mm/s3)	85869.57 (59997.25)	54573.68 (36117.33)	2.265	.030*
Mean of jerk (mm/s3)	8243.48 (2220.49)	7207.50 (1759.50)	2.017	.048*
Standard deviation of jerk (mm/s3)	5003.26 (1789.28)	4059.47 (1124.35)	2.535	.030*
Standardized jerk (mm/s3)	217094.67 (75810.46)	182365.51 (48898.31)	2.178	.058

Note: * p <.05, ** p <.01. ADHD - Attention-deficit Hyperactivity Disorder.

Table 2, Table 3, Table 4, and Table 5 demonstrate the participants' performance of pursuit flexibility on four speeds. Among 12 kinematics variables, two groups displayed significantly difference on 4 variables in the slowest speed (30mm/s) of pursuit flexibility. As speed increased, more variables differed significantly between groups (i.e. 5 variables on 50mm/s test; 7 variables on 80mm/s test; 10 variables on 100mm/s test).

Discussion

The study done by Slaats-Willemse and colleagues (2005) has measured only the result of average displacement and standard deviation of movement during individual implementations, but it has failed to mention about the quality of the movement process. This study combines the touch screen and analysis software to capture the kinematic performance of participant's movement process with their natural and habitual posture. In kinematic measurements, increase in movement speed and acceleration represents greater forces used by the participant; whereas the jerk increases, the process of performance is likely to be less smooth.

Previous literature have discovered that children with ADHD, who cannot concentrate or have combination symptoms, display the greatest peak value of forces during the implementation of finger tapping tests, of which signifies that the child is lack of control in hand strength (Pitcher, Piek and Barrett, 2002). Children with symptoms of ADHD and developmental coordination disorder apply faster velocity in movement than the normal children (Flapper et. al, 2006). When the children with ADHD try to connect the start and end points together on the monitor using the stylus and tablet, the peak acceleration performance is greater than the control group, with poor accuracy of movement and unable to accurately connect the line to the finishing point. This shows that children with ADHD have poorer controls in motor plans and motor control (Eliasson, 2004).

The results of this study have also found that when children with ADHD implement various speeds of dexterity during the Pursuit Tests, regardless how fast the asterisk moves about on the monitor, they still use faster speed in pen-movement to pursuit the asterisks than the normal children. Additionally, the standard deviation for speed is greater during the pursuit process, indicating greater variation in speed of pen movement and the difficulty of using consistent speed during the implementation. When the velocity of asterisks is greater than 50 millimeters per second, ADHD child's maximum acceleration and maximum deceleration are significantly higher than the children in the normal control group. This means that, during the implementation of tests, children with ADHD may perform using greater physical strength and the achieved maximum value of strength may also be higher than those of the normal children, hence indicating that children with ADHD show problems in lack of control for movement planning and speed.

In respect to the smoothness of movement, when implementing the motor flexibility of asterisks by increasing the speed to 30mm per second, the value of jerk, which represents the degree of smoothness in movement, shows no significant difference from the value obtained by the children in the control group. When the asterisk increases in speed, the maximum and the average values of jerk for children with ADHD become significantly higher than the normal children in the control group. This shows that, when the speed of the test increases during the implementation, the degree of smoothness in pen movement will also become less. Furthermore, when the asterisk is moving at a faster speed, children with ADHD will also have greater standard deviation value of jerk than the normal children in the control group, which indicates the reason of unable to maintain the degree of smoothness during the implementation. However, in each test of speed, there is no significant difference noted in the standard value of jerk among these two groups of children. The reason may be that the standard value of jerk and the values of individual displacements are related to the time in which the movement is implemented. By having all participants execute movements consistently at the same time, and that the average and standard deviation values of displacements are similar to the results, it is safe to infer that the displacement in movements for the two groups will be similar, thus resulting in no significant difference in the standard value of jerk among these two groups. As for the performance of the number of inversions in velocity and acceleration, both the ADHD and the normal control groups show no significant difference. However, exception occurs when the asterisk speeds to 100mm per second, in which there is a significantly higher number of inversions in velocity for the Children with ADHD than those of the children in the normal control group.

Barkley (1998) proposed that children with ADHD have difficulty on movement control in the complex activities that involved planning, self-regulation and higher-order cognitive processes. Schneider and Shiffrin (1997) believed activities involving higher-order cognitive processes would have required continual maintenance and attention. In this study, pursuit flexibility test required participants to maintain one minute of focused attention and to adjust the control of movement simultaneously, thus required higher level of cognitive process capabilities.

The children with ADHD in this study have been tested in situations where the asterisks are moving at various speeds. When the asterisks move at slower speed (V=30mm/s), many of the kinematic variables cannot reach the statistical difference. However, when the speed of the asterisk increases, the maximum acceleration and deceleration are significantly greater for the children of ADHD than the children in the normal control group, as well as reaching the statistical difference. In addition, with the asterisk moving at the maximum speed, it can be noted that Children with ADHD display a significantly greater value of jerk than the normal children, which means that when the speed increases, Children with ADHD have less smoothness in the process of movement . Previous studies have also found that self-control already exists in children of preschool age, as well as higher levels of cognitive functions, such a self-adjustment and recognition of defects in processing (Kalff, et al., 2003). Thus, this study has also confirmed that the movement process is less smooth for Children with ADHD, and that flaws exist in the implementations, which require high-functioning cognitive processing.

According to the motor control theory, the writing performance could be divided into the closed-loop movement control and the open-loop movement control. Open-loop movements relied mainly on feed-forward mechanisms, meaning that movements were executed based on one's own velocity and ideas. Contrary, closed-loop movements depended upon the feedback mechanisms to adjust one's movement as necessary, therefore required constant maintenance of attention throughout the movement process (Freund, 1986; Shumway-Cook and Woollacott, 2001). The pursuit flexibility test in this research required the visual feedbacks acquired by the testers to maintain the focus of attention in accepting stimulation from external information and to adjust the movement, thus closer related to the closed-loop movements. In year 2001, Siebner and colleagues had discovered that writing movement of closed-loop and the cerebrum senses and sensory-motor cortex, lateral premotor cortex, left anterior parietal cortex, left anterior putamen, the left rostral supplementary motor area, and right precuneus are closely related. Connection between the attention control and the lateral premotor cortex was also demonstrated during the execution of closed-loop movements in the research (Jenkins, Brooks, Nixon, Frackowiak, Passingham, 1994; Jueptner et al., 1997). Currently, other studies also confirmed that an ADHD child has a smaller capacity in the sensorimotor cortex than that of a normal person (Mostofsky, Cooper, Kates, Denckla, and Kaufmann, 2002). Thus, while this group performs the test of pursuit flexibility, the outcome of the performance might be inferior, for possible damages might exist in the sensorimotor cortex in the frontal cerebrum area, as well as poor control in attention focus.

In clinical implications, this study has found that Children with ADHD display flaws in the quality of movements, and their performance during movements is less smooth in comparison with normal children. Furthermore, the higher the level of cognitive processing and the faster the movements, the problem of less smoothness becomes more apparent for children of ADHD. Therefore, based on motor learning theory, when focusing on the motor rehabilitation for Children with ADHD, as well as enhancing the movement quality, the children can begin by performing task at a slower pace and allowing additional time for repetitive practices. Once the children achieve a good level of movement quality, then the speed can be increased gradually and slowly, and as a result, improve the problem of movement quality for Children with ADHD.

Due to the limited sample size in this research, recommendations are made to be caution on using the findings from this research, and the recruitment of more participants is suggested to reaffirm the study results. Moreover, because the Children with ADHD participated in this research demonstrated acceptable cognitive functioning, the results might not be generalized to all ADHD population. In addition, this study used the touch-sensor monitors with the capability of 30 sample recordings per second, much less than the touch-sensor monitors used by Slaats-Willemse in 2005, which collected 60 sample recordings per second. This factor might have caused bias to occur during kinematic data collection. Therefore, the use of digital tablets is suggested in the future for better recording the movement process. Besides, the researchers have also observed that Children with ADHD tend to use greater force on pursuit flexibility control. Hence, future researches should try to combine strain gauge and EMG measurements to detect the amount of hand strength or finger forces being used during the movement tests.

The literature indicates that ADHD drugs may affect a child's motor performance. O'Driscoll et al. (2005) have found that methylphenidate would improve the capacity of movement planning for children with ADHD. Tucha and Lange (2001) have also discovered that methylphenidate would enhance the quality and accuracy of children's writing; while the Flapper et al. (2006) have found that children with ADHD and developmental coordination disorder are taking medications show improvements object manipulation and writing quality. They have noticed that when children with ADHD and developmental coordination disorder do not take methylphenidate, the movements are less accurate, but the process moves more smoothly. While taking the medication, their motor performances are more accurate, but the action process is less smooth. The reason is because the drug causes children with ADHD to maintain focus on the activities, hence uses slower speed to adjust the actions, thus results in a more accurate motor performance. Relatively speaking, a greater variation in speed indicates the less smoothness of movements. In most studies on nerve movements in children with ADHD, the participants have stopped taking the drugs approximately 12 to 48 hours prior the tests. In this study, about 70% of children with ADHD were treated with drugs and they stopped taking medications one day before the test. This is much less in comparison to Flapper and colleague's criteria in 2006, whose study allowed children to stop taking drugs up to 4 weeks in advance. Thus, whether this study can completely rule out the impacts of taking the medication on long-term basis remains unknown. It is suggested that future researches can explore the effects of medications for children with ADHD in motor control and movement quality, and to determine whether differences exist.

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