Introduction

The Diagnostic and Statistical Manual of Mental Disorders 5th edition (DSM-5) characterizes autism spectrum disorder (ASD) by deficits in social communication and social interaction as well as restricted, repetitive patterns of behavior, interests or activities [1]. In addition to the main peculiarities, it is well known that persons with ASD demonstrate various motor impairments, such as impaired gross motor function, motor coordination and manual dexterity [2−6]. These impairments are also referenced in DSM-5 [1]. Those difficulties have a large impact on activities of daily living as well as social activities in persons with ASD.

There is literature on handwriting difficulty in children with ASD. Several studies have demonstrated handwriting impairments in ASD using a standard assessment battery of handwriting [7−13]. A previous study suggested that more than 65% of persons with ASD have handwriting difficulties [8]. Handwriting is a highly important skill for schoolchildren to achieve academic progress, acquire language and build self-esteem.

Fuentes et al. suggested that general motor skills could predict handwriting impairments in children with ASD [10]. However, they used the score for gross motor functions to represent motor skills, therefore, it remains unclear how hand and finger movements affect their

Hand and Finger Functions and Characteristics of Line Drawing Movement in Preschool Children with Autism Spectrum Disorder: Preliminary Study

Kaori Yamaguchi, Ph.D., OTR¹, Misako Sano, Ph.D, OTR², Reiko Fukatsu, Ph.D., MD³

¹ School of Health Sciences at Narita, International University of Health and Welfare
² National Rehabilitation Center for Children with Disabilities
³ Research Institute of National Rehabilitation Center for Persons with Disabilities

Abstract: It is well known that children with autism spectrum disorder show handwriting difficulty. Although it is considered that not only cognitive but also motor impairments affect the difficulty, remarkably little is known about the motor characteristics of handwriting in autistic children. Therefore, the purpose of this study is to investigate: 1) peculiarities of hand and finger functions; and 2) characteristics of handwriting movement in preschool children with ASD during the chrysalis stage of handwriting. Participants were children with ASD and age- and partially IQ-matched controls. We conducted assessment of muscle strength, motor coordination, separate finger movement, dexterity, grasp posture and line drawing movement. We compared data between ASD and control groups. Significant differences were observed in repetitive hand tapping, pronation and supination, sequential finger tapping, finger lifting and pegboard. Considering components of handwriting, there seems to be no prominent difference between the two groups in grasp posture, although ASD showed poorer motor coordination on the drawing line task compared to that of controls. The present results also showed atypical characteristics of hand and finger motor functions and line drawing movement in ASD. These findings provide further insight into the motor aspects of handwriting and suggest investigating correlation between hand and finger functions, especially separate finger movement and manual dexterity and motor aspect of handwriting may be important to clarify effective bottom up training for acquisition of handwriting skills.

Keywords: handwriting, developmental disorders, tool use, motor coordination
handwriting skill.

Writing is a complex behavior involving motor control, visual perception, language, memory and other functions. Considering its motor aspects, it is a complex tool use activity and adequate hand and finger motor development is essential for skillful writing. Hand and finger function is required for appropriate pen grip and fine adjustments while drawing and writing [14]. There are a few studies demonstrating relevance between hand and finger function and handwriting in normal, healthy children. Schneck showed correlation between pencil grip pattern and writing skill [15] and Berninger and Rutberg found that finger functions (e.g., finger tapping, finger lifting and finger cognition) correlated with writing skills in early elementary school children [16]. Finger lifting is a test for separate finger movement and it is necessary for approximate posture of pen grip and fine control of a pen point [14, 17, 18]. In clinical settings, children with ASD who had lower performance on separate finger movement test showed difficulty in manipulating a writing utensil [19].

As described above, even though hand and finger function is known to be important for handwriting, little is known about these functions in ASD. Dufield et al. reported ASD showed lower performance on functional tests such as grip power, tapping and pegboard, but subjects in their study showed a wide age range from 5 to 33 years old [20]. Thus, there is no information about these functions in preschool children who are acquiring handwriting skill. Clarifying the development of hand and finger functions and its relation to handwriting in ASD is expected to contribute to the establishment of efficient interventions to address these difficulties.

Therefore, the purpose of this study is to investigate: 1) peculiarities of hand and finger functions; and 2) characteristics of handwriting movement in preschool children with ASD during the chrysalis stage of handwriting. As a preliminary study, we conducted several tests and tasks for this research; tests of muscle strength, motor coordination, separate finger movement and dexterity and assessment of grasp posture and line drawing task. Line drawing task was selected to focus on motor aspects of writing, while minimizing the influence of cognitive aspects as much as possible.

Methods

Participants

This study examined 17 children with and without ASD. Subjects were eight children diagnosed with ASD aged 4–6 (yrs.) and nine age- and nonverbal IQ-matched children demonstrating typical developmental milestones as controls. A summary of subjects is shown in Table 1. Children in control group were recruited with leaflet in community around the research institute where this study was conducted. Regarding ASD group, there was child and adolescent psychiatrist among cooperative researchers and children with ASD were recruited from her patients. Children with ASD were diagnosed with autism spectrum disorder following DSM-5 criteria or diagnosed Pervasive Developmental Disorder and Asperger’s Syndrome following DSM-4 revised criteria. In addition, all subjects were evaluated by the Japanese version of the Social Responsiveness Scale (SRS) [21]. SRS is a standardized battery for assessment autistic traits for individuals aged 4 to 18 years. It consists of 65-items questionnaire categorized into five subscales; social awareness, social cognition, social communication, social motivation and autistic mannerism. T-score calculated by raw score and standard deviation is applied to assess autistic trend. The score above 76 is considered as “ASD-possible”, from 60 to 75 as “ASD-probably” and bellow 59 as “ASD-unlikely”. Diagnoses were confirmed in all ASD children by scores above the cutoff value and all control children were confirmed as not having ASD by scores below the cutoff value on SRS (Table 1). All subjects had a full-scale IQ (FIQ) greater than 75 and Perceptual Reasoning Indices (PRI) greater than 80 on the Wechsler Intelligence Scale for Children, 4th edition (WISC-IV) [22]. There are significant differences in FIQ and primary index scores except for PRI between two groups. PRI was considered the primary intelligence measure for our study since we employed a nonverbal, motor-based task. None of the subjects was receiving any medication. None of the controls had any history of neurological or psychiatric disorders. All

| number | age (yrs.) | SRS T score (range) | full IQ | VCI | PRI | WMI | PSI |
|--------|------------|---------------------|---------|-----|-----|-----|-----|
| ASD    | 8 (M:F = 6:2) | 5.6 | 70.8 (61–105) | 82.4 | 82.1 | 92.4 | 76.3 | 91.3 |
| controls | 9 (M:F = 4:5) | 5.6 | 41.9 (40–51) | 104.8 | 104.0 | 103.5 | 96.6 | 108.0 |

Subject backgrounds are shown in the table. All data from “age” to “PSI” are presented as the average of the group. Range of SRS T score is presented in brackets. Items of “Full IQ” to “PSI” are the results of intelligence quota assessments on WISC-IV. “VCI”, “PRI”, “WMI” and “PSI” indicating Verbal Comprehension Index, Perceptual Reasoning Index, Working Memory Index and Processing Speed Index, respectively.
Subjects had normal or corrected-to-normal vision and no one had any detectable sensory abnormality of the hands or fingers. Each subject could understand the task instructions and was able to continuously concentrate their attention on the task for at least 30 minutes while maintaining an appropriate posture. All participants were right handed according to the results of Edinburgh Handedness Inventory [23] as well as an interview with their parents about activities of daily living.

Prior to the study, written informed consent was obtained from the parents of each child in a manner approved by the ethical committee of the National Rehabilitation Center for Persons with Disabilities in accordance with the Declaration of Helsinki.

**Materials and Procedure: Assessments for hand and finger functions**

Assessments for hand and finger motor functions, muscle strength (grip and lateral pinch), motor coordination (hand tapping, pronation and supination, finger tapping and sequential finger tapping), separate finger movement and fine motor skills (Perdue pegboard), were conducted. All assessments were basically conducted for both hands. We applied some parts of Zurich Neuromotor Assessment: ZNA which is standardized assessment of duration and degree of motor functions [24] for assessment of motor coordination. “Hand tapping” requires movement of tapping knee with one hand repeatedly and “finger tapping” requires movement of tapping with thumb and index finger. Participant is asked to repeat the movement 20 times and the duration is measured. “pronation and supination” is task of pronation and supination with forearm repeatedly. Ten sets of movements (pronation and supination are one set) is required and the duration is measured. In the task of “sequential finger tapping”, participant is required to tapping with their fingers; thumb and the other fingers. The tapping is done in order of thumb-index finger, thumb-middle finger, thumb-ring finger and thumb-little finger. Three sets of order are required and the duration is measured [24]. For separate finger movement, we applied a modified version of the test developed by Wolff et al. [17]. Subjects were asked to put their hands palms-down on the table and lift the finger touched by the experimenter in random sequence. They were asked to immediately lift the touched finger only. We evaluated voluntary control of separate finger movements by counting how many other fingers lifted when the child tried to lift the touched finger only.

**Materials and Procedure: Components of handwriting**

We measured pen grasping posture and line drawing movement as components of handwriting.

Pen grasping posture was evaluated using a five-part score (score of 1 indicating the lowest and 5 the highest) on Pencil-Grip Assessment by Schneck and Henderson [25].

Subjects were asked to draw a 2 cm straight line using a pen-type writing pressure gauge (DP-1000 USB version; Japan System Development Co., Ltd) to measure motor elements. We recorded pen pressure as power control and trajectory of line as motor coordination. Subjects were asked to draw a line from dot to dot within the limited space. They moved the pen point forward at their own speed without touching either of the parallel lines (Fig. 1). We referred to standard assessment battery; Developmental Test of Visual Perception (DTVP), subtests 1, visuomotor coordination to fix the task setting [26]. The line drawing task consisted of two conditions ranked by difficulty in order to investigate whether their movement is affected by a difference in the visual information provided during the task. Two parallel lines were presented in order to designate the limits of the drawing space and subjects were asked to draw a line between the parallel lines. The parallel lines were 2cm apart in the easy condition and 2mm apart in the difficult condition. Two dots were presented as the starting and ending points of drawing line. Before the trials, subjects practiced a few times to confirm their understanding of the instructions. The task was limited to 12 trials in order to avoid tiring the subjects. Six trials were in the easy condition, while the other six were in the difficult condition. Each child held the pen with their dominant hand in their own grasp posture.

**Statistical analysis**

We conducted statistical analyses of all test results to compare ASD to controls. All data were analyzed using R (version 3.1.0.). Because there were few subjects, we applied Wilcoxon rank sum test as a nonparametric test.
Results

Although all subjects in both groups completed the tests and task, data on finger lifting, pegboard, pen force and deviation from one or two subjects in the ASD group were considered unreliable because they appeared to respond facetiously. Therefore, those data were excluded from analysis. Ultimately data from six participants for finger lifting, pen force and deviation and data from seven participants for pegboard in ASD were statistically analyzed. Results of assessments for hand and finger functions and components of handwriting were shown in Figs. 2, 3.

Assessments for hand and finger functions

We compared data of hand and finger functions between ASD and control groups (Fig. 2). Measured value of muscle strength, time durations of motor coordination test, score of separate finger movement and fine motor skills were applied. Significant differences were observed in repetitive hand tapping on the left side ($p = 0.02$), pronation and supination on the right and left sides ($p = 0.001, p < 0.001$ respectively), sequential finger tapping on the right and left sides ($p = 0.001, p = 0.04$ respectively), finger lifting on the right and left sides ($p = 0.01, p < 0.001$ respectively), and pegboard on the right and left sides (single hand use) ($p = 0.01, p < 0.01$ respectively).

Components of handwriting

Considering grasp posture, that of all participants in both groups were scored at the level 4 or 5. There were four grasp types observed; Four-finger grasp and Cross thumb grasp as in level 4 and Lateral tripod grasp and Dynamic tripod grasp as in level 5 (Fig. 3). There were no prominent differences between the two groups.

For the line drawing task, we evaluated deviation of the line trajectory to evaluate motor coordination based on differences between the length of the actual drawn line and a straight 2 cm line connecting the two dots. There was significant difference in deviation in the difficult condition ($p = 0.01$) (Fig. 3). Thus, deviation demonstrated the degree of motor coordination. ASD group showed poorer motor coordination than controls.

Furthermore, two participants in ASD whose results of deviation were superior to the others got better results
in finger lifting and pegboard among ASD group.

Discussion

We investigated: 1) hand and finger motor functions; and 2) components of handwriting in ASD. Persons with ASD show motor impairments in some areas. In this study, we demonstrated atypical motor characteristics in ASD that have not been reported previously.

Hand and finger functions

ASD showed significantly lower performance on both sides for pronation and supination, sequential finger tapping, finger lifting and pegboard (single hand use). Our results were consistent with those of previous studies demonstrating impairments in manual dexterity [4, 20, 27]. Duffield et al. reported that ASD showed significantly lower performance on finger tapping and pegboard test, but not on grip strength [20]. For grip strength and pegboard, our results were consistent with their research. Simple finger tapping did not show a significant difference between groups in our study, although there was a difference in their study. The smaller number of subjects in our study may have affected the result. Previous structural or functional neuroimaging studies also support our findings in terms of atypical neural patterns in ASD [20, 28, 29]. The lower performance on sequential finger tapping and finger lifting test in ASD indicates a developmental delay in separate finger movement. Previously, Virginia and Berninger reported a correlation between handwriting and both sequential finger tapping and finger lifting in normal children [16]. Investigating correlation between separate finger movement and handwriting skill in ASD is required.

Components of Handwriting

Certain characteristics of line drawing were observed in ASD. Slightly less pen force was observed in ASD, although the difference did not reach significance. Deviation was significantly larger for ASD than controls in the difficult condition. Heuvel et al. previously reported that in normal adults, pen force increased for large targets and decreased for small targets [30], that is, pen force decreased under more difficult conditions. Our results for both controls and ASD were consistent with those findings. Since there was no difference in hand or finger strength between groups, the lower pen force in ASD may indicate that appropriate power control is difficult for ASD. Larger deviation in ASD suggests impaired sensorimotor coordination, especially visuomotor coordination. Glazebrook et al. and Rinehart et al. reported that ASD exhibited more spatial variability during reaching tasks [31–33]. Papadopoulos et al. showed more widely variable errors in ASD during a reciprocal reaching task [34]. It may be beneficial that influence of impaired motor coordination on handwriting in ASD.
There seems to be no difference in grasp posture between groups. Considering previous literature [15, 16], handwriting difficulty in ASD may be caused by motor impairment rather than grasp posture.

Although we could not analyze correlation between hand and finger functions and handwriting components in this study, in ASD group, two children who scored better in deviation performed better in finger lifting and pegboard. The result may suggest that separate finger movement and manual dexterity are factors of skill of drawing line regarded as motor aspects of handwriting.

Limitations and Recommendations for Further Research

There are methodological limitations of our study. In the study, eight autistic children and nine control children participated. Limited number of participants might have influenced the findings. Gender and IQ differences except for PRI might be another factor. In addition, participants were asked to perform a limited number of trials for each condition in order to avoid their loss of interest in doing the same task repeatedly. Recruiting more autistic and control participants whose IQ are totally equal and analyzing the correlation between hand and finger functions and characteristics of drawing line should be considered in future studies.

Summary and Conclusions

The present results showed atypical characteristics of hand and finger motor functions and line drawing in ASD. These findings provide further insight into the motor aspects of handwriting in ASD. Investigating correlation between hand and finger functions, especially separate finger movement and manual dexterity and motor aspect of handwriting may be suggested to clarify effective bottom up training for acquisition of handwriting skills.

Conflict of Interest

The authors affirm that there were no conflicts of interest related to this study.

Acknowledgements: This work was supported by Health and Labor Sciences Research Grants in Japan.

References

[1] Diagnostic and Statistical Manual of Mental Disorders. 5th ed. American Psychiatric Association, 2013.
[2] Manjiviona J, Prior M. Comparison of Asperger syndrome and high-functioning autistic children on a test of motor impairment. J Autism Dev Disord. 1995; 25: 23–39.
[3] Leary MR, Hill D. Moving on: autism and movement disturbance. Ment Retard. 1996; 34: 39–53.
[4] Green D, Baird G, Barnett AL, Henderson L, Huber J, Henderson SE. The severity and nature of motor impairment in Asperger's syndrome: a comparison with Specific Developmental Disorder of Motor Function. J Child Psychol Psychiatry. 2002; 43: 655–68.
[5] Ming X, Brimacombe M, Wagner GC. Prevalence of motor impairment in autism spectrum disorders. Brain Dev. 2007; 29: 565–70.
[6] Staples KL, Reid G. Fundamental movement skills and autism spectrum disorders. J Autism Dev Disord. 2010; 40: 209–17.
[7] Beversdorf D, Anderson J. Brief report: macrographia in high-functioning adults with autism spectrum disorder. J Autism Dev Disord. 2001; 31: 97–101.
[8] Mayes SD, Calhoun SL. Frequency of reading, math, and writing disabilities in children with clinical disorders. Learn Individ Differ. 2006; 16: 145–57.
[9] Cartmill L, Rodger S, Ziviani J. Handwriting of Eight-Year-Old Children with Autism Spectrum Disorder: An Exploration. J Occup Ther Sch Early Interv. 2009; 2: 103–18.
[10] Fuentes CT, Mostofsky SH, Bastian AJ. Children with autism show specific handwriting impairments. Neurology. 2009; 73: 1532–7.
[11] Fuentes CT, Mostofsky SH, Bastian AJ. Perceptual reasoning predicts handwriting impairments in adolescents with autism. Neurology. 2010; 75: 1825–9.
[12] Kushki A, Chau T, Anagnostou E. Handwriting difficulties in children with autism spectrum disorders: a scoping review. J Autism Dev Disord. 2011; 41: 1706–16.
[13] Hellinckx T, Roeyers H, Van WH. Predictors of handwriting in children with Autism Spectrum Disorder. Res Autism Spectr Disord. 2013; 7: 176–86.
[14] Henderson A, Pehoski C. Hand Function in the Child: Foundations for Remediation. 2nd ed. Science Direct, 2006.
[15] Schneck C. Comparison of pencil-grip patterns in first graders with good and poor writing skills. Am J Occup Ther. 1991; 45: 701–6.
[16] Virginia W. Berninger JR. Relationship of finger function to beginning writing: application to diagnosis of writing disabilities. Dev Med Child Neurol. 1992; 34: 198–215.
[17] Wolff PH, Gunnoe CE, Cohen C. Associated movements as a measure of developmental age. Dev Med Child Neurol. 1983; 25: 417–29.
[18] Largo RH, Caflisch JA, Hug F, Muggli K, Molnar AA, Molinari L. Neuromotor development from 5 to 18 years. Part 2: associated movements. Dev Med Child Neurol. 2001; 43: 444–53.
[19] Yamaguchi K., Fukatsu R. Handwriting intervention for preschool children with developmental disorders (in Japanese). Japanese Occupational Therapy Research
(sagyou ryouhou). 2016; 35(4): 426–35.

[20] Duffield TC, Trontel HG, Bigler ED, Froehlich A, Prigge MB, Travers B, et al. Neuropsychological investigation of motor impairments in autism. J Clin Exp Neuropsychol. 2013; 35: 867–81.

[21] Kamio Y, Inada N, Moriwaki A, Kuroda M, Koyama T, Tsujii H, et al. Quantitative autistic traits ascertained in a national survey of 22,529 Japanese school children. Acta Psychiatr Scand. 2013; 128: 45–53.

[22] Wechsler D. Antonil S, ed. Wechsler Intelligence Scale for Children. Fourth Edition. NCS Pearson, Inc, 2013.

[23] Oldfield RC. The assessment and analysis of handedness: the Edinburgh Inventory. Neuropsychologia. 1971; 9: 97–113.

[24] Largo RH, Caflisch JA, Hug F, Muggli K, Molnar AA, Molinari L, et al. Neuromotor development from 5 to 18 years. Part 1: timed performance. Dev Med Child Neurol. 2001; 43: 436–43.

[25] Schneck CM, Henderson A. Descriptive Analysis of the Developmental Position for Pencil and crayon control in nondysfunctional children. Am J Occup Ther. 1990; 44: 893–900.

[26] Frostig M. Developmental Test of Visual Perception. Consulting Psychologists Press, Inc, 1977.

[27] Hardan AY, Kilpatrick M, Keshavan MS, Minshew NJ. Motor performance and anatomic magnetic resonance imaging (MRI) of the basal ganglia in autism. J Child Neurol. 2003; 18: 317–24.

[28] Müller RA, Pierce K, Ambrose JB, Allen G, Courchesne E. Atypical patterns of cerebral motor activation in autism: a functional magnetic resonance study. Biol Psychiatry. 2001; 49: 665–76.

[29] Mostofsky SH, Powell SK, Simmonds DJ, Goldberg MC, Caffo B, Pekar JJ. Decreased connectivity and cerebellar activity in autism during motor task performance. Brain. 2009; 132: 2413–25.

[30] Heuvel CEVD, Galen GPV, Teulings HL, Gemmert AWA. Axial pen force increases with processing demands in handwriting. Acta Psychiatr (Amst). 1998; 100: 145–59.

[31] Glazebrook C, Elliott D, Lyons J. A kinematic analysis of how young adults with and without autism plan and control goal-directed movements. Motor Control. 2006; 10: 244–64.

[32] Glazebrook CM, Elliott D, Szatmari P. How do individuals with autism plan their movements? J Autism Dev Disord. 2008; 38: 114–26.

[33] Rinehart NJ, Bellgrove MA, Tonge BJ, Brereton AV, Howells RD, Bradshaw JL. An examination of movement kinematics in young people with high-functioning autism and Asperger’s disorder: further evidence for a motor planning deficit. J Autism Dev Disord. 2006; 36: 757–67.

[34] Papadopoulos N, McGinley J, Tonge BJ, Bradshaw JL, Saunders K, Rinehart NJ. An investigation of upper limb motor function in high functioning autism and Asperger’s disorder using a repetitive Fitts’ aiming task. Res Autism Spectr Disord. 2012; 6: 286–92.