Determinants of fine manual dexterity in adolescents and young adults with Down's syndrome

Chih-Chia (J.J.) Chen[1], Shannon D.R. Ringenbach[2]

[1]Department of Kinesiology, Mississippi State University, Starkville, Mississippi, USA; [2]School of Nutrition and Health Promotion, Arizona State University, Phoenix, Arizona, USA

Background: To date, numbers of studies have indicated the important role of fine manual dexterity in typical and special populations. However, the relevant studies in Down's syndrome (DS) population is still limited. The purpose of this study was to investigate the determinants of manual dexterity in adolescents and young adults with DS.
Methods: Thirty participants with DS (22 males, 8 females, aged 13–31) were screened by anthropometric variables (i.e. sex, chronological age, verbal intelligence, body mass index), levels of physical activity, and sleep disorders, and were administered the Purdue Pegboard Test and the Choice Reaction Time Test. Measures of correlation, *t*-test and multiple regression model were used for data analysis.
Results: It was indicated that sex and sleep-related disorders during the day explained 37.2% of the variance in the performance of the Purdue Pegboard Test. The additional of 9.7% can be explained the variance by adding reaction time test performance. Verbal intelligence had the negatively relation with the performance of non-Dominant Hand and Bimanual subtests of the Purdue Pegboard Test.
Conclusion: This study suggested that sex, sleep disorder, and neuromotor function may be the important determinants of fine manual dexterity performance in adolescents and young adults with DS. In addition, the level of intelligence might also exert the effect on fine motor development in this population. In order to design effective interventions and optimize manual performance in individuals with DS, these possible determinants should be considered. Future research should be replicated with large sample size, different age groups, and validated measures of finger size, physical activity and sleep behaviors.

Keywords Intellectual disabilities, Purdue pegboard, Motor control, Sleep

1. Introduction

The literature has indicated Down's syndrome (DS) is one of the common genetic disorders in intellectual disability (ID). In addition to cognitive impairment, DS is also characterized as motor deficits. Previous studies focused on the development of gross motor skills and suggested that individuals with DS are incapable to produce typical movement patterns because of their muscular, skeletal and neurological dysfunctions peers (Galli et al. 2008; Galli et al. 2008). For example, individuals with DS have an increase in frequency oscillation both in anterior-posterior and medio-lateral directions during postural control and showed ligament laxity, joints stiffness and low propulsive capacity at push-off during locomotion compared with their typical peers. Recently, numbers of studies became interested in the development of fine motor skills (e.g., manual dexterity) because of its positive associations between academic performance and auditory naming (Katsipataki 2013; Pexman and Wellsby, 2016; Vuijk et al. 2011). On the other hand, Chen et al. (2014a) were interested in final motor performance in individuals with DS. They noted that adolescents and young adults with DS who performed better in manual dexterity, assessed using the Purdue Pegboard Test, showed better cognitive planning capacity, assessed using the Tower of London Test. In addition, Chen and Ringenbach (2015) indicated a negative relationship between sleep disorder behaviors (e.g., obstructive sleep apnea (OSA), daytime sleepiness) and the scores in the Purdue Pegboard Test for participants with DS. Therefore, it seems like the development of fine motor performance is not compartmentalized. It is a complexity system of reciprocal changes among different functions, such as executive functioning and sleep problems, in individuals with DS.

Correspondence to: Chih-Chia (J.J.) Chen, Department of Kinesiology, Mississippi State University, Mississippi State, MS 39762, USA, Email: cc2196@msstate.edu

DOI 10.1080/20473869.2019.1665783

Furthermore, patients with neurodegenerative diseases, such as Alzheimer's disease (AD) and Parkinson's disease, exhibit a progressive impairment of cognitive decline. In the early symptomatic stages, this cognitive decline may precede functional decline in activities of daily living that is associated with the deficits in fine manual dexterity. Thus, manual dexterity is a voluntary activity to manipulate objects, which involves the integration of motor and cognitive functions. To date, fine manual dexterity, assessed using the Purdue Pegboard Test, has been widely applied to identify the early onset of neurodegenerative diseases (Darweesh et al. 2016; Kluger et al. 1997). For example, Kluger (1997) noted that motor tasks were able to distinguish typical elderly, patients with mild cognitive impairment as well as AD as effectively as cognitive tests of memory and language. Hence, motor impairment could be an important aspect of cognitive decline. As for individuals with DS, the performance of manual dexterity has fallen behind compared to their chronological-aged matched peers and mental-aged matched peers (Gardner and Broman 1979; Mathiowetz et al. 1986). Dolva et al. (2004) reported that only 11% and 0% of 5-year-old children with DS were able to perform tooth brushing and tying shoelaces respectively. Manual dexterity seems to be also an important indicator for self-care domains of daily life in individuals with DS. Therefore, the deficits in fine manual dexterity might be reflective of a high incidence of AD in individuals with DS (Lott and Head 2001). To our best knowledge, the Purdue Pegboard Test has been one of the popular dexterity tests for individuals with ID and DS as well (Aylward et al. 1997; Carmeli et al. 2008; Esposito et al. 2017). In order to understand the application and research of the Purdue Pegboard Test in individuals with DS, Chen and Ringenbach (2015) tested the reliability of the Purdue Pegboard Test in adolescents and young adults with DS and demonstrated its moderate to high test-retest reliability in this population. Hence, the Purdue Pegboard Test would be adopted in the current study due to its a reliable measurement tool to assess fine manual dexterity in individuals with DS.

Moreover, Riley and Cochran (1984) examined the manual dexterity performance of 35 males and 35 females and indicated sex was a significant predictor for the Purdue Pegboard Test performance. The males performed better on an assembly subtest, while the females performed better on dominant-hand and non-dominant hand subtests. Currently, Haapala et al. (2016) indicated that adiposity and physical activity levels were related to neuromuscular performance, including manual dexterity in schoolchildren. Children who had higher body fat percentage and lower levels of physical activity had slower 50-m shuttle run and 15-m sprint times, short distance jumped in standing long jump test, few sit-ups, more errors in balance test and less cubes moved in box-and-block test. Additionally, D'Hondt et al. (2009) indicated the relationship between motor skills and body mass index (BMI). They found obese children had poor scores in manual dexterity performance compared to their ideal-weight peers. In individuals with DS, Chen and his colleagues reported other possible factors that may contribute to the development of fine manual dexterity. Chen et al. (2014a) noted a positive relationship between the performance of Purdue Pegboard Test and The Tower of London Test. Participants with DS who placed more pieces solved more puzzles in The Tower of London Test. Further, Klotz et al. (2012), compared to typical controls, children with ADHD had slower and more variable reaction times and this finding was correlated with slow finger sequencing. Thus, the neuromotor function (e.g., reaction time and movement time) may be shared in motor and cognitive tasks when participants finished tests in the given time. In addition, sleep disorders should be considered as well. Chen and Ringenbach (2015) indicated some sleep behaviors, such as obstruct sleep apnea (OSA) and daytime sleepiness, in individuals with DS were associated with their poor performance in the Purdue Pegboard Test. In particular, a 30-year follow up study showed that many individuals with ID experienced major changes as early as in their 20 s and 30 s in physical performance and manual dexterity (Lahtinen et al. 2007). However, prior literature did not to adequately address other possible factors in individuals with DS. In order to enhance their fine manual dexterity performance and prevent the risk of AD in individuals with DS, more studies will be needed to understand the determinants of fine manual dexterity performance in adolescents and young adults with DS.

Given the known relationships between manual dexterity and its relationships between sex, level of intelligence, body composition, physical activity level, neuromotor function, and sleep disorder behaviors. This study was an extension of previous work to systematically investigate the possible determinants of fine manual dexterity, assessed using the Purdue Pegboard Test, in adolescents and young adults with DS. Based on previous findings in typical populations and individuals with DS, the present study investigated two issues. First, we hypothesized sex, level of intelligence, body composition, physical activity level, neuromotor function, and sleep disorder behaviors would be related to the performance of the Purdue Pegboard Test. Second, the possible determinants would be applied to explain the variance in manual dexterity performance.

2. Methods

2.1. Participants

A total of thirty participants (22 males, 8 females, aged 13-31) were recruited from a variety of local organizations (e.g., Down syndrome network, and local Special

Olympics programs, etc.). Interested parents/guardians were given a description of the task and eligibility requirements for participation via telephone or email. The Peabody Picture Vocabulary Test (3rd Ed.; PPVT-III) was used to measure the receptive processing and verbal intelligence of participants. If his/her verbal intelligence was below 3-year-old, he/she would be excluded from this study. The mean of verbal intelligence was 6.04 ± 1.80 years.

The vision and hearing assessments were also conducted. The vision was tested using a standard eye chart (i.e., Snellen) or a modified version which consists of E's pointing in different directions for participants who could not recognize letters. The hearing was tested using an audiometer (the Maico Ma 25). If participants did not have at least 20/100 vision or was considered as hard of hearing, he/she would be also excluded in the study. The purpose of these assessments was to ensure they were able to understand the instructions and perform the test. In the current study, no participants were excluded. Based on our multiple resources and methods we believe that our sample is representative of the Down's syndrome population. All protocols were approved by the Human Subjects Institutional Review Board of our University.

2.2. Measures

2.2.1. Anthropometric variables

Chronological age (CA) was assessed by parental-report. Body mass index (BMI) was computed by dividing weight by the square of height (kg/m^2).

2.2.2. Peabody picture vocabulary Test- III (PPVT-III)

The Peabody Picture Vocabulary Test is to measure verbal ability in standard American English vocabulary. It is utilized to measure the receptive processing and verbal intelligence in individuals with intellectual disabilities (ID). A stimulus word was orally presented to each participant with a set of numbered pictures and then the participant was requested to select the picture that best represented the meaning of the stimulus word. A significant relationship has been found between PPVT-III and verbal IQ scores in Wechsler Intelligence Scale for Children-Revised among students with ID (Beck and Black 1986). Thus, the raw scores of PPVT-III in this study were converted into an age-equivalent score as the verbal intelligence of each participant.

2.2.3. Godin Leisure-Time exercise questionnaire (GLTEQ)

Godin Leisure-Time Exercise Questionnaire (GLTEQ) was a recall questionnaire for parents/guardians to measure the level of leisure-time physical activity for their children during a 7-day period. The frequencies of strenuous, moderate, and mild activities were multiplied by nine, five, and three respectively. These three values represent as the metabolic equivalent (MET) value. The total level of PA was computed by summing the products of strenuous, moderate and light components. The GLTEQ has been shown a correlation with VO_2max ($r = 0.24$, $p < 0.001$) (Godin and Shephard 1985). Thus, the score in GLTEQ in the study can be represented as the physical fitness level of each participant.

2.2.4. Sleep disorders questionnaire

The Sleep Questionnaire is a 7-point Likert Scale, originally developed by Simonds and Parraga (SQ-SP; 1982). It is a parental rating of sleep disorders for their children. Stores et al. (1996) further adapted this version to explore sleep disorders in individuals with DS. Four factors of sleep disorders are discussed from SQ-SP, including 1) Disorders of initiating and maintaining sleep, such as bedtime resistance; 2) Features associated with OSA, such as snoring or gasping for breath; 3) Disorders occurring during sleep, such as nightmares or sleepwalking; and 4) Disorders occurring during the daytime, such as daytime sleepiness, naps or daytime overactivity. The test-retest reliability for the total SQ-SP score is r = .83 to 1.00. There are six items in Disorders of initiating and maintaining sleep, features associated with OSA, and sleep related disorders/behaviors occurring during the day with a possible range of 6 to 42. There are eight items in Disorders/behaviors occurring during sleep with a possible range from 8 to 56. In this study, a higher total score is represented sever sleep disorders.

2.2.5. Choice reaction time test (CRT)

Each participant was required to place the right index finger on one button corresponding to a blue light and place the left index finger on the other button corresponding to a white light. Each trial, the participant would be reminded to press the corresponding button as soon as possible while the specific visual stimulus (e.g., blue and white lights) was seen. Then, the visual stimulus was presented after the verbal cue. The time between each visual stimulus and the verbal cue varied (randomly) between 1 and 3 seconds. Five practice trials were given to ensure the understanding of instructions and ten testing trials were conducted. The CRT is not only affected by the degree of motor impairment but the interaction between cognitive processing and motor speed compares to simple reaction time (Pullman et al. 1988). Thus, in this study, the mean of testing trials represented the performance in neuromotor function.

2.2.6. Purdue pegboard test

First, a seven-item handedness inventory was used to test handedness (Oldfield 1971). Participants were instructed physically to write with a pen, draw a circle with a pen, use scissors, use a hammer, throw a ball,

Table 1 Descriptive statistics of participants ($n = 30$)

Variable	Mean	s.d.
Chronological Age (CA, years)	21.26	5.46
Mental Age (MA, years)	6.04	1.80
Height (cm)	147.96	9.91
Weight (kg)	73.63	23.47
Body Mass Index (BMI, kg/m^2)	32.55	10.78
Physical Activity Level (MET/min/week)	34.97	26.28
Choice Reaction Time Test (ms)	645.04	265.37
Sleep Disorders		
Disorders of Initiating and Maintaining Sleep	7.57	2.46
Features associated with OSA	14.00	6.81
Other Disorders Occurring During Sleep	10.87	2.56
Sleep related Disorders Occurring during the Day	9.67	4.50
Purdue Pegboard Test		
Dominant Hand Subtest	7.64	2.28
Non-Dominant Hand Subtest	7.43	1.86
Bimanual Subtest	5.25	1.62
Assembly Subtest	10.01	2.87
Manual Dexterity Scores	30.36	7.81

pretend to brush their teeth, and pretend to eat with a spoon. If four out of seven items were performed with his/her by either right or left hand, it was deemed as the dominant hand and the other hand as the non-dominant hand.

The Purdue Pegboard Test (Lafayette Instrument Model #32020) consists of a board with four subtests: Dominant hand, Non-Dominant hand, Bimanual and Assembly. Each subtest was administered three times in a row. The dominant hand and non-dominant hand subtests required to place as many pegs as possible in the column corresponding to the hand being tested within 30-sec. The dominant hand is tested first followed by the non-dominant hand. In the bimanual subtest, both hands simultaneously placed a pair of pegs in both columns. The scores on these three tests were the pairs of pegs for the bimanual subtest, placed within 30-sec. The assembly subtest required picking up and placing pegs, washers, collars and second washers using alternating hands. This score represents the number of pieces assembled within 60-sec.

2.3. Testing procedure

Upon arriving at the Research Laboratory, the parents/guardians completed an informed consent form, demographic questionnaire (e.g., behavior checklist, medical history). The demographic questionnaire was used to screen for previous health issues that may impair their motor and cognitive tasks performance. Next, the participant performed PPVT-III, vision test and hearing test to confirm their capacities to perform all the tests. After completing the questionnaires and assessments, the participant was asked to perform Purdue Pegboard Test and CRT. The entire testing procedure lasted on average 30-min.

2.4. Data analysis

Data were analyzed with the Statistical Package for the Social Sciences, SPSS 23.0. The data were followed a normal distribution. Bonferroni-corrected Student t test in the case of difference in Purdue Pegboard Subtests between sex groups to determine if sex is responsible for this difference. The statistical significance was considered to be $p \leq .0125$. Next, a Pearson Product-Moment Correlation Coefficient was used to evaluate the strength of the relationships between the performance in the Purdue Pegboard Test and the other potential confounding factors (i.e., sex, CA, verbal intelligence, height, weight, BMI, PA level, sleep disorder behaviors and CRT) (two-tailed). In addition, the linear regression analysis (backward method) was used to investigate the influence of related factors analysis was carried out to identify the factors that were most highly correlated with the total scores in the Purdue Pegboard Test in adolescents and young adults with DS. The level of significance was set at $p \leq .05$

3. Results

The total of 30 adolescents and young adults with DS (mean age = 21.5 yr) participated in the current study. Their CA, verbal intelligence, BMI, the level of PA, sleep disorders, and the performance in CRT and Purdue Pegboard Test were listed in Table 1.

3.1. Sex difference in the purdue pegboard test performance

As seen in Table 2, females significantly performed better than males in non-Dominant Hand (Females: 9.12 ± 1.13, Males: 6.82 ± 1.67, $t = –3.57$, $p = .01$) and Bimanual (Females: 6.99 ± 0.71, Males: 4.61 ± 1.36, $t = –4.70$, $p < .001$). The marginally significant level was approached in Dominant Hand (Females: 9.13 ± 2.13, Males: 7.10 ± 2.12, $t = –2.30$, $p = .02$) and Assembly (Females: 11.99 ± 1.61, Males: 9.29 ± 2.91, $t = –2.48$, $p = .02$) subtests of the Purdue Pegboard Test. Hence, sex might be a significant predictor for manual dexterity for participants with DS.

3.2. Correlations with the purdue pegboard test performance

As shown in Table 3, Person Product-Moment Correlations identified the possible confounding factors that significantly affected the manual dexterity performance. The performance in CRT ($r = –.46$, $p = .01$) and sleep-related disorders occurring during the day ($r = –.50$, $p = .005$) were found to be significantly negative relations to the scores in the Purdue Pegboard Test. The marginally significant relationship was found for MA ($r = .34$, $p = .06$) and level of PA ($r = –.33$, $p = .07$) to the manual dexterity performance. Particularly, MA was significantly positive relations to Non-Dominant

Table 2 Gender difference in the performance of purdue pegboard test ($n = 30$)

Measures	Male (N = 22)	Female (N = 8)	*t*	*P*
Purdue Pegboard Test				
Dominant Hand Subtest	7.10 (2.12)	9.13 (2.13)	−2.30	0.02
Non-Dominant Hand Subtest	6.82 (1.67)	9.12 (1.13)	−3.57	0.01*
Bimanual Subtest	4.61 (1.36)	6.99 (0.71)	−4.70	<0.01*
Assembly Subtest	9.29 (2.91)	11.99 (1.61)	−2.48	0.02

*$p \leq .0125$.

Table 3 Correlations between manual dexterity and variables ($n = 30$)

	CA	MA	Height	Weight	BMI	PA	Sleep[1]	Sleep[2]	Sleep[3]	Sleep[4]	CRT
Dominant Hand Subtest	−.08	.28	−.26	−.08	−.03	−.33	−.23	−.18	.06	−.36	−.35
Non-Dominant Hand Subtest	.11	.46*	.03	.08	.23	−.30	.22	.34	.77	.06	−.41*
Bimanual Subtest	.04	.39*	−.16	.02	.003	−.31	−.08	−.22	−.16	−.52*	−.44*
Assembly Subtest	.19	.21	−.04	.19	.15	−.27	−.16	−.32	−.14	−.53*	−.49*
Manual Dexterity Scores	.08	.34	−.11	.06	.05	−.33	−.14	−.28	−.02	−.50*	−.46*

*$p \leq .05$.

Note. CA = Chronological Age; MA = Mental Age; BMI = Body Mass Index; PA = Physical Activity Level; Sleep[1] = Disorders of Initiating and Maintaining Sleep; Sleep[2] = Features associated with OSA; Sleep[3] = Other Disorders Occurring During Sleep; Sleep[4] = Sleep related Disorders occurring during the day; CRT = Choice Reaction Time.

Hand ($t = .445$, $p = .01$) and Bimanual ($t = .391$, $p = .03$) subtests of the Purdue Pegboard Test. Thus, sleep-related Disorders occurring during the day and neuromotor function may exert the impact on manual dexterity performance in participants with DS.

3.3. Regression model to predict manual dexterity

As indicated in Table 4, multivariate linear regressions were used to identify factors that significantly predict the performance of manual dexterity in participants with DS. Model 1 noted that sex and sleep-related disorders occurring during the day significantly explain 37.2% of the variance of the performance in the Purdue Pegboard Test. Both variables were significant contributors. Model 2 demonstrated that the additional 9.7% variance of the performance in the Purdue Pegboard Test can be explained after adding the performance in CRT into the model. All three variables were significant contributors in Model 2.

4. Discussion

The purpose of this study was to explore the determinants of manual dexterity, assessed using the Purdue Pegboard Test, in adolescents and young adults with DS. First, this study indicated that sex, the performance in CRT, and sleep-related disorders occurring during the day were associated with the performance in the Purdue Pegboard Test. In addition, multiple regression models were extended to investigate the effects of those variables on manual dexterity in individuals with DS. The total of 37.2% of the variance in fine manual dexterity can be explained by sex and sleep-related disorders occurring during the day. An addition of 9.7% variance of manual dexterity can be explained after considering their neuromotor function.

Partially inconsistent with Riley and Cochran (1984), female participants with DS were able to place more objects in the given time than male participants with DS in all four subtests. Similarly, Bryden and Roy (2005) indicated that females had superior performance in the grooved pegboard test because their movement were 7 seconds faster than males. Peters and Campagnaro (1996) further assumed the difference in finger size between males and females might be the contributing factor. They noted that males showed better performance for holding thick pegs, whereas females showed better performance for holding thin pegs. Further, Housman (1997) and Marshall (2007) reported a negative relationship between the finger size and the performance in the Purdue Pegboard Test. Both studies suggested that the finger size might be important to predict fine manual dexterity. Thus, In the current study, the female participants who might be small sized fingers performed well in the pegs place task. On the other hand, prior literature in individuals with DS did not consider sex as a possible variable that determined the performance in dexterity test performance. Therefore, it is recommended that sex and finger size variables should be included in the future study for manual dexterity performance in individuals with DS.

Furthermore, consistent with Chen and Ringenbach (2015), sleep-related disorders during the day (e.g., daytime sleepiness) had a negative effect on the performance of Purdue Pegboard Test in individuals with DS. It was possible that the high prevalence of excessive daytime sleepiness might result in their deficit in attentional focus during participation. Strenge et al. (2002) found the similar phenomenon in typical participants and supported the idea that attention should be an important determinant of the performance for manual dexterity tests. However, the connections between the features of OSA and any subtests of the Purdue

Table 4 Hierarchical ordinary least squares regression models estimating effects of gender, sleep disorders, and neuromotor function on manual dexterity ($n = 30$)

	Model 1			Model 2		
Variables	B	SE	β	B	SE	β
Gender	7.38	2.70	.42*	5.88	2.60	−.34**
Sleep[4]	−.65	.27	−.37*	−.630	.250	−.36*
CRT				−.010	.040	−.23****
(Constant)	27.270	5.040		214.55.30	60.630	
F		9.58*			9.11*	
Adjusted R^2		.372***			.456***	
Change in Adjusted R^2					.097	

*$p \leq .05$.
Note. Sleep[4] = Sleep related Disorders occurring during the day; CRT = Choice reaction time.

Pegboard Test were not evident in the current study. Chen and Ringenbach (2018) indicated that the features of OSA was inversely related to walking distance in adolescents and young adults with DS. It seems like sleep disorder behaviors might affect differently on the developments in gross and fine motor skills in individuals with DS. Further, this study did not fully support the evidence that the engagement in physical activity may help maintain dexterity and coordinated hand function. McGregor et al. (2013) suggested that the increased physical fitness was associated with the increased levels of interhemispheric inhibition in the primary motor cortex, which regulated upper extremity motor performance and may contribute to better manual dexterity in healthy adults. Hence, it was possible that parents might not be with their children with DS all day and not be able to report all the sleep disorder behaviors and physical activity levels for their children with DS. Future studies would need more validated measures in individuals with DS to understand the mediating role of sleep disorder behaviors and physical activity levels in the development of fine manual dexterity for individuals with DS.

Moreover, the neuromotor function aspect of cognition seems to be important for fine manual dexterity performance in individuals with DS. Consistent with Esposito et al. (2017), the association between reaction time and fine manual dexterity was noted in adults with ID. It can be assumed that executive function was highly involved during the Purdue Pegboard Test because individuals with DS needed to exert much cognitive processing resource to follow the rules and update the information all the time. In addition, the influence from the level of intelligence should not be overlooked. Our results indicated that MA was associated with the performance in non-Dominant Hand and Bimanual subtests of the Purdue Pegboard Test. Participants who had higher verbal intelligence seemed to placed more pieces in the current study. However, verbal intelligence did not become a significant predictor in the current study. It might be because the range of verbal intelligence was controlled between 5 and 8 years old. Lastly, inconsistent with previous studies in healthy populations (D'Hondt et al. 2009; Haapala et al. 2016), adiposity was not related to the manual dexterity performance. It was possible that the high prevalence of obesity was seen among the participants. There were twenty-one participants who were categorized as overweight/obesity based on their BMI values. Thus, adiposity may show less influence on the performance in the Purdue Pegboard Test among participants with DS. Future studies need to recruit the individuals with DS with different levels of intelligence and ideal-weight BMI to distinguish the role of MA and adiposity on the fine motor development.

In fact, some limitations should be noted in the current study. First, some biological/physiological factors, such as finger size, have been reported to be associated to the performance in the Purdue Pegboard Test (Aylward et al. 1997; Marshall 2007). Thus, future study the measurement of finger size to investigate the biological structure and neural connectivity in individuals with DS. In addition, the small sample size could be one of the limitations although there were several significant determinants. To our knowledge, the relevant studies in Purdue Pegboard Test for children and aging with DS are scarce. Our preliminary results seem to be promising but need to be replicated with a larger sample with many different age groups (e.g., children and aging with DS) and body composition (e.g., ideal weight, overweight) to validate the current findings. Lastly, future studies should conduct objective instruments or direct measures of sleep disorder behaviors (e.g., polysomnography) and physical activity levels (e.g., accelerometer) to obtain accurate information in individuals with DS.

In summary, this is the first study that explored some support for the associations between the fine manual dexterity, sex, sleep disorder behaviors and neuromotor function in individuals with DS. These preliminary results are promising but need to be replicated with a larger sample and more physiological and objective measures to enhance our understanding of fine motor development for individuals with DS. Liubicich et al. (2012) noted that elderly participants could improve their fine manual dexterity in residential care facilities after a 16-week physical activity program. In addition, it has been demonstrated that assisted-

cycling exercise intervention may stimulate motor cortex and further improve fine motor performance in special populations (Chen et al. 2014b; Ridgel et al. 2009). Therefore, parents, teachers and practitioners may encourage individuals with DS to participate in regular physical activity program in order to improve their fine manual dexterity that prevent from cognitive decline in their later lives.

Disclosure statement

The authors have no conflicts of interest to declare in reference to this work.

References

Aylward, E. H., Habbak, R., Warren, A. C., Pulsifer, M. B., Barta, P. E., Jerram, M. and Pearlson, G. D. 1997. Cerebellar volume in adults with Down syndrome. *Archives of Neurology*, 54, 209–212.

Beck, F. W. and Black, F. L. 1986. Comparison of PPVT-R and WISC-R in a mild/moderate handicapped sample. *Perceptual and Motor Skills*, 62, 891–894.

Bryden, P. J. and Roy, E. A. 2005. A new method of administering the Grooved Pegboard Test: performance as a function of handedness and sex. *Brain Cognition*, 58, 258–268.

Carmeli, E., Bar-Yossef, T., Ariav, C., Levy, R. and Liebermann, D. G. 2008. Perceptual-motor coordination in persons with mild intellectual disability. *Disability and Rehabilitation*, 30, 323–329.

Chen, C. C. and Ringenbach, S. D. R. 2018. Walking performance in adolescents and young adults with Down syndrome: the role of obesity and sleep problems. *Journal of Intellectual Disability Research*, 62, 339–348.

Chen, C.-C. (J.) and Ringenbach, S. D. 2015. Test-retest reliability of Purdue Pegboard in individuals with Down syndrome. *Journal of Motor Learning and Development*, 3, 151–157.

Chen, C.-C. (J.)., Ringenbach, S. D. R., Albert, A. and Semken, K. 2014. Fine motor control is related to cognitive control in adolescents with Down syndrome. *International Journal of Disability, Development and Education*, 61, 6–15.

Chen, C. C., Ringenbach, S. D. R and Albert, A. R. 2014. Assisted cycling exercise improves fine manual dexterity in persons with Down's Syndrome. *Journal of Applied Research in Intellectual Disabilities*, 27, 264–272.

Darweesh, S. K. L., Wolters, F. J., Hofman, A., Stricker, B. H., Koudstaal, P. J. and Arfan Ikram, M. 2016. Simple test of manual dexterity can help to identify persons at high risk for neurodegenerative diseases in the community. *The Journals of Gerontology: Series A*, 72, 75–81.

Esposito, P., Cole, W., Giovinazzo, B., and Owens, L. (2017). Reaction time and fine motor dexterity in adults with intellectual disabilities. *American Journal of Occupational Therapy,* 71(4_Supplement_1), 7111500043p1-7111500043p1.

Dolva, A.S., Coster, W and Lilja, M. 2004. Functional performance in children with Down syndrome. *American Journal Ofoccupational Therapy*, 58(6), 621–629.

D'Hondt, E., Deforche, B., Bourdeaudhuij, I. De. and Lenoir, M. 2009. Relationships between motor skill and body mass index in 5-to 10-year-old children. *Adapted Physical Activity Quarterly*, 26, 21–37.

Galli, M., Rigoldi, C., Brunner, R., Virji-Babul, N. and Giorgio, A. 2008. Joint stiffness and gait pattern evaluation in children with Down syndrome. *Gait & Posture*, 28, 502–506.

Galli, M., Rigoldi, C., Mainardi, L., Tenore, N., Onorati, P. and Albertini, G. 2008. Postural control in patients with Down syndrome. *Disability and Rehabilitation*, 30, 1274–1278.

Gardner, R. A and Broman, M. 1979. The Purdue pegboard: Normative data on 1334 school children. *Journal of Clinical Child Psychology*, 8, 156–162.

Godin, G and Shephard, R. J. 1985. A simple method to assess exercise behavior in the community. *Canadian Journal of Applied Sport Science*, 10, 141–146.

Haapala, E.A., Väistö, J., Lintu, N., Tompuri, T., Brage, S., Westgate, K., Ekelund, U., Lampinen, E.-K., Sääkslahti, A., Lindi, V. and Lakka, T. A. 2016. Adiposity, physical activity and neuromuscular performance in children. *Journal of Sports Science*, 34, 1699–1706.

Housman, G.S. (1997). An analysis of fingersize and performance on the Purdue pegboard dexterity test (Doctoraldissertation, Austin Peay State University).

Katsipataki, M. 2013. Can motor skills training improve academic performance? A structured motor skills intervention for young children. Unpublished Doctoral thesis. Durham University.

Klotz, J. M., Johnson, M. D., Wu, S. W., Isaacs, K. M. and Gilbert, D. L. 2012. Relationship between reaction time variability and motor skill development in ADHD. *Child Neuropsychology*, 18, 576–585.

Kluger, A., Gianutsos, J. G., Golomb, J., Ferris, S. H., George, A. E., Franssen, E. and Reisberg, B. 1997. Patterns of motor impairment in normal aging, mild cognitive decline and early Alzheimer's disease. *Journal of Geronotology*, 52B, 28–39.

Lahtinen, U., Rintala, P and Malin, A. 2007. Physical performance of individuals with intellectual disability: A 30-year follow-up. *Adapted Physical Activity Quarterly*, 24, 125–143.

Liubicich, E.M., Magistro, D., Candela, F., Rabaglietti, E. and Ciairano, S. 2012. Physical activity, fine manual dexterity and a coach's self-efficacy in a physical activity program for older persons living in residential care facilities. *Psychology*, 3, 384–392.

Lott, I.T and Head, E. 2001. Down syndrome and Alzheimer's disease: a link between development and aging. *Mental Retardation and Developmental Research: Research Review*, 7, 172–178.

Oldfield, R.C. 1971. The assessment and analysis of handedness: The Edinburgh inventory. *Neuropsychologia*, 9, 97–114.

Mathiowetz, V., Rogers, S. L., Dowe-Keval, M., Donahoe, L. and Rennells, C. 1986. The Purdue Pegboard: Norms for 14- to 19-year-olds. The *American Journal of Occupational Therapy*: *Official Publication of the American Occupational Therapy Association*, 40, 174–179.

Marshall, S.N. 2007. The influence of sex and finger size on fine motor task performance. (Unpublished master's thesis). Southern Illinois University at Carbondale, Carbondale, IL.

McGregor, K.M., Nocera, J. R., Sudhyadhom, A., Patten, C., Manini, T. M., Kleim, J. A., Crosson, B. and Butler, A. J. 2013. Effects of aerobic fitness on aging-related changes of interhemispheric inhibition and motor performance. *Frontiers in Aging Neuroscience*, 5, 66.

Peters, M and Campagnaro, P. 1996. Do women really excel over men in manual dexterity? *Journal of Experimental Psychology: Human Perception and Performance*, 22, 1107–1112.

Pexman, P.M and Wellsby, M. 2016. Linkinghand to mouth. The relationship between manual dexterity and language skills intypically-developing children. Reti. *Saperi, Linguaggi*, 3(1), 81–94.

Pullman, S. L., Watts, R. L., Juncos, J. L., Chase, T. N. and Sanes, J. N. 1988. Dopaminergic effects on simple and choice reaction time performance in Parkinson's disease. Neurology, 38, 249–254.

Ridgel, A. L., Vitek, J. L and Alberts, J. L. 2009. Forced, not voluntary, exercise improves motor function in Parkinson's disease patients. *Neurorehabilitation & Neural Repair*, 23, 600–608.

Riley, M. W and Cochran, D. J. 1984. Dexterity performance and reduced ambient temperature. *Human Factors*, 26, 207–214.

Simonds, J. F and Parraga, H. 1982. Prevalence of sleep disorders and sleep behaviours in children and adolescents. *Journal of the American Academy of Child Psychiatry*, 21, 383–388.

Stores, R., Stores, G and Buckley, S. 1996. The pattern of sleep problems in children with Down's syndrome and other intellectual disabilities. *Journal of Applied Research in Intellectual Disabilities*, 9, 145–159.

Strenge, H., Niederberger, U and Seelhorst, U. 2002. Correlation between tests of attention and performance on grooved and Purdue pegboards in normal subjects. *Perceptual and Motor Skills*, 95, 507–514.

Vuijk, P.J., Hartman, E., Mombarg, R., Scherder, E. and Visscher, C. 2011. Associations between academic and motor performance in a heterogeneous sample of children with learning disabilities. *Journal of Learning Disability*, 44, 276–282.