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Motor functions of higher education students with dysgraphia

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A R T I C L E I N F O

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A B S T R A C T

This study examines the motor skills and motor-related daily functions of higher education students with and without dysgraphia, and their contribution in predicting handwriting performance. The sample included 82 higher education students aged 20–35 years old. Thirty-four were students without any known developmental disorder (NDD) and 48 students had dysgraphia. We individually administered a test battery evaluating handwriting performance, fine-motor skills, and visual-motor spatial-organization skills. Students also filled out a questionnaire relating to their fine- and gross-motor-related daily functions. Overall, the NDD students had significantly better motor skills and motor-related daily functions. Additionally, the motor skills and daily functions explained 62.9% of the variance in handwriting performance, and they correctly classified 90% of the students into the handwriting performance groups. Yet only visual-motor spatial organization and fine-motor-related daily functions significantly contributed to the fit of the model. These findings suggest that students with dysgraphia continue to encounter handwriting difficulties in higher education. These difficulties are linked to poor motor skills and motor-related daily functions. Therefore, higher education students with dysgraphia may require assistance and accommodations throughout their studies, not only with regard to their academic performance, but also in their motor-related daily functions.

What this paper adds

The knowledge relating to the characteristics of students with dysgraphia and associated motor functions is extremely limited. Our findings showed that, similar to handwriting, the motor difficulties of students with dysgraphia and their impact on daily functions do not disappear with age, but rather continue into adulthood. One of the major factors that contributes to these difficulties is a deficit in visual-motor spatial organization. Therefore, higher education students with dysgraphia may require services and accommodations throughout their studies.

1. Introduction

Higher education students with specific learning disabilities (SLD) encounter difficulties in various academic areas, including reading, math and written expression (American Psychiatric Association, 2013; Graham & Harris, 2013). Written expression along with spelling and handwriting are often considered manifestations of dysgraphia. These manifestations of dysgraphia may present together or separately (Berninger, Richards, & Abbott, 2015; McCloskey & Rapp, 2017; Prunty & Barnett, 2017). However, in this study we focused on handwriting difficulties, because handwriting is a core aspect of dysgraphia (Berninger et al., 2015; McCloskey &

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Rapp, 2017).

Students with dysgraphia may have poor legibility (Graham, Fishman, Reid, & Hebert, 2016; Parush, Lifshitz, Yochman, & Weintraub, 2010), write slowly, and/or experience pain and fatigue while writing (Parush, Levanon-Erez, & Weintraub, 1998). These difficulties may be the result of different deficits, including linguistic, cognitive, or motor functions (Berninger & Richards, 2010; Nicolson & Fawcett, 2011); thus, students with dysgraphia comprise a heterogeneous group.

One of the implications of dysgraphia is that it may limit students' ability to demonstrate their knowledge and ideas, because in many countries students are still required to take handwritten exams (Barnett, Henderson, Scheib, & Schulz, 2009; Peverly, Garner, & Vekaria, 2014). Consequently, their self-esteem and motivation may be diminished (Engel-Yeger, Nagauker-Yanuv, & Rosenblum, 2009). Moreover, being a learned motor activity, one may assume that the underlying motor deficits leading to dysgraphia may also affect other daily life activities. Hence, students with dysgraphia may also have difficulties in motor-based daily activities. Yet, the current knowledge relating to the motor skills and motor-related daily functions of higher education students with dysgraphia is limited.

1.1. Handwriting process and underlying motor functions

Handwriting is acquired through a long process of learning and practice. Different models have been developed to describe this complex activity (Palmis, Danna, Velay, & Longcamp, 2017). One of the most commonly studied models was developed by Van Galen (1991). This model describes handwriting as a hierarchical and parallel process that includes several stages. The first is the retrieval of internalized motor programs that consist of information required for producing the selected allographs (specific letter forms) to be written. In the second stage, the writer sets the visual-spatial parameters for writing; i.e., decides where to place the letters on the page or line (Graham, Struck, Santoro, & Berninger, 2006). In the third stage, the writer sets the size parameters for executing the motor program. These stages are followed by the recruitment of the muscles to stabilize the body and to manipulate the writing tool (including the amount of force), leading to the handwriting of the intended text (Van Galen, 1991).

Analysis of these stages suggests that the handwriting process requires various motor functions. Support for this premise is found in studies showing that individuals with motor functions such as developmental coordination disorder (DCD), expressed in difficulties with motor control, anticipatory planning, and reduced automatization of movement skills, often show handwriting difficulties (Barnett, Henderson, Scheib, & Schulz, 2011; Blank et al., 2019; Wilson et al., 2017). These difficulties were noted in students' handwriting products (i.e., legibility) in terms of letter formation and spatial organization of the text on the paper (Prunty & Barnett, 2017; Rosenblum, Margieh, & Engel-Yeger, 2013). Lower performance among children with DCD was also reported in relation to the handwriting process, including slower writing and more pauses, compared to NDD students (Prunty, Barnett, Wilmut, & Plumb, 2014; Rosenblum et al., 2013).

Various studies showed a relationship between visuo-motor-spatial organization and handwriting performance. For example, several researchers reported an association between visual-motor integration (VMI), which requires the integration of visual-spatial perception and organization as well as motor control (Kaiser, Albaret, & Doudin, 2009), and handwriting performance among early elementary school students (Brossard-Racine, Majnemer, Shevell, Snider, & Bélanger, 2011, 2015; Brown & Link, 2015). These correlations were less prominent among older students in elementary school (Goyen & Duff, 2005; Prunty, Barnett, Wilmut, & Plumb, 2016). Other researchers reported that VMI differentiated between elementary school students classified as good or poor handwriters, where students with poor handwriting scored significantly lower on a task measuring VMI, compared to students with good handwriting (Duiser, van der Kamp, Ledebt, & Savelsbergh, 2013; Klein, Guiltner, Sollereder, & Cui, 2011).

In addition, researchers have reported a relationship linking fine-motor sequential movement, finger dexterity, and handwriting performance among elementary school students (Berninger & Rutberg, 1992; Brown & Link, 2015; Kaiser, Schoemaker, Albaret, & Geuze, 2015; Klein et al., 2011; Wilson et al., 2017) as well as adults (Weintraub, Gilmour-Grill, & Weiss, 2010). These fine-motor functions were also found to be lower among students with poor handwriting, compared to their peers with good handwriting (Klein et al., 2011; Weintraub & Graham, 2000).

1.2. Motor-related daily functions of individuals with dysgraphia

Similar to handwriting, many daily functions require motor learning and execution. Therefore, difficulties in acquiring and performing motor skills may affect aspects of daily life activities. Yet, there is a paucity is studies describing the motor-related daily functions of individuals with dysgraphia. By contrast, both children and young adults with DCD, who often have handwriting difficulties (Prunty et al., 2014) have been reported to have difficulties in various daily activities requiring fine-motor skills, such as using eating utensils, tying shoelaces, dressing, and keyboarding (Blank et al., 2019; Bo & Lee, 2013). Individuals with DCD have also been reported to have difficulties with gross-motor related daily functions such as playing ball games, riding a bicycle, participating in sports activities, and driving (Barnett, Hill, Kirby, & Sugden, 2015; Blank et al., 2019; Gagnon-Roy, Jasmin, & Camden, 2016; Tal-Saban, Ornoy, & Parush, 2016; Van der Linde et al., 2015; Wilson et al., 2017; Zwicker, Suto, Harris, Vlasakova, & Missiuna, 2018). Therefore, it is reasonable to suggest that the motor difficulties related to handwriting performance may also affect daily functions.

1.3. Higher education students with dysgraphia

The prevalence rate of dysgraphia among higher education students is unknown. There is accumulating evidence that individuals with neuro-developmental disabilities, specifically individuals with SLD and DCD, do not outgrow their difficulties (Blank et al., 2019; Tal-Saban, Ornoy, & Parush, 2014). Therefore, the handwriting difficulties experienced in childhood may likely continue during higher education studies. The few available studies concerning higher education students showed that those with SLD and with DCD had difficulties in handwriting performance, expressed in their handwriting speed, automaticity, legibility, and tidiness (Barnett et al., 2011; Kirby, Edwards, Sugden, & Rosenblum, 2010; Weigelt-Marom & Weintraub, 2015). This group may be heterogeneous with co-occurring deficits (Berninger & Richards, 2010; Brossard-Racine et al., 2015; Nicolson & Fawcett, 2011). However, in our study we focused on the motor deficits related to the handwriting performance of students with dysgraphia.

1.4. Study purpose

This study had several objectives: (a) to compare the motor performance and motor-related daily functions of students with and without dysgraphia; (b) to examine the associations linking fine-motor skills, motor-related daily functions, and handwriting; and (c) to examine the unique and joint contributions of motor functions in predicting group affiliation (having or not having dysgraphia). Although we could not find previous studies on this topic, we expected to find lower fine-motor and motor-related daily functions among students with dysgraphia, compared to their NDD peers. We also expected that these motor functions would predict students' group affiliation regarding dysgraphia. These postulations were based on the following factors: (a) studies relating to children (reviewed above) showing the relationship between handwriting and motor performance, and specifically among students with DCD; (b) the fact that handwriting is a learned motor activity requiring automatization that individuals with handwriting difficulties often lack (Palmis et al., 2017); and (c) the psychomotor handwriting model (Graham et al., 2006; Van Galen, 1991) describing the spatial organization and fine-motor requirements of the handwriting process. The results of this study will increase our knowledge of the links between motor functions and handwriting disorders of this population, as well as their motor-related daily functions. The study may also enhance our understanding of the underpinnings of dysgraphia among higher education students.

2. Methods

2.1. Participants

Originally, the study sample included 95 higher education students between the ages of 20–35 years whose mother tongue is Hebrew. We recruited the students from various academic settings. The sample encompassed two groups: students with a specific SLD (a reading or writing disorder) who also had dysgraphia (henceforth, students with dysgraphia), and students without any known developmental disorder (NDD). The students with dysgraphia were included in the study if: (a) they were diagnosed with a specific learning disorder as defined by the Diagnostic and Statistical Manual of Mental Disorders-Fifth Edition (DSM-5; American Psychiatric Association, 2013) and received accommodations based on a valid assessment from the past 5 years; and (b) they had difficulties in handwriting functions verified by a standardized test ($Z <$ -1.5 or lower on the HaPPS; see below in the Measures section). If the students also had attention deficit hyperactivity disorder (ADHD), they were tested while under medication. Students were excluded from the study if they: (a) had a neurosensory loss (e.g., blindness), or (b) had a physical disability (including an upper limb, neck and/or back problem in the past 6 months). In addition, the NDD students were excluded if they: (a) reported that they were previously diagnosed with a SLD or other neurodevelopmental disorder (e.g., ADHD, DCD), and (b) were found to have handwriting difficulties. Overall 6 students were excluded.

2.2. Measures

2.2.1. Student background questionnaire

This measure was designed as an open-ended questionnaire to collect demographic data (e.g., age, gender), developmental and medical background (e.g., developmental milestones attained, physical or occupational therapy received, diseases, medication use), occupational background (current and previous work), history of diagnosis of learning disabilities, and past/present educational background (e.g., acquisition of basic academic skills, grades).

2.2.2. Handwriting Performance of Post-Secondary Students Evaluation (HaPPS; Weintraub, Israeli-Ovadia, Shoval, & Traub-Bar-Ilan, 2012)

The HaPPS was developed for the purpose of evaluating the handwriting performance of higher education students. It consists of four tasks: copying a paragraph for 10 min, writing to dictation for 3 min, an expository writing composition for 5 min, and the Alphabet task (based on Abbott & Berninger, 1993). The tasks are evaluated for speed (number of characters, letters, and punctuation marks per minute) and legibility (percent of unreadable words). The alphabet task was not used in this study. The HaPPS was found to have a medium-high and statistically significant inter-rater reliability for legibility in copying ($.61 < r < .87$, $p < .05$). It is important to note that in this study the HaPPS served two purposes. First, it was the basis for determining eligibility for the study by identifying individuals with handwriting difficulties, based on their copying, dictation and expository writing. Second, we used the copying task to examine correlations between motor and handwriting performance.

2.2.3. Adult Self Report Scale-v1.1- Part A. (ASRS; Kessler et al., 2005)

The ASRS-v1.1 is designed to screen adults with possible ADHD. It is comprised of 18 questions describing ADHD symptoms based on the DSM-IV (APA, 1994) criteria. The first subset of the ASRS (Part A) is composed of six questions found to be the most predictive of the disorder. The ASRS-v1.1- Part B (the next 12 questions of the scale) may be used to fully assess a patient's ADHD symptoms (Murphy & Adler, 2004). In the current study we used only Part A and applied the updated scoring rules to predict DSM-5 (American Psychiatric Association, 2013) diagnoses, based on the work of Ustun et al. (2017), to develop a DSM-5 update to the original ASRS screening scale. Difficulty in attention was determined by a score of 11 or higher in Part A.

2.2.4. Finger succession (Berninger & Rutberg, 1992; Denckla, 1973)

The purpose of this task is to examine the speed of performing a sequential fine-motor task. It also reflects kinesthetic ability because the task is performed when the hands are out of peripheral vision. Scoring is based on the time (seconds) it takes the student to complete five correctly performed cycles.

2.2.5. The Purdue Pegboard Test (PPT; Tiffin, 1960)

The PPT is a standardized measure of finger speed and dexterity widely used in clinical and research settings for individuals aged 15 and older. It includes four subtests, each yielding a separate score: manipulation of pegs using the preferred (dominant) hand, the nonpreferred hand, both hands together, and an assembling (sequencing) task. Each subtest is scored for the number of pegs placed in the board in a predetermined time. Validity and reliability are well established through extensive research in healthy and patient populations (Yancosek & Howell, 2009).

2.2.6. Rey complex figure test and recognition trial (RCFT; Meyers & Meyers, 1995)

The RCFT is standardized measure of visual-spatial construction and memory for individuals aged 18 and older. It includes three tasks: one of copying and two of recall. In this study, we employed only the copying task, examining visual-motor spatial organization. Although time was measured, students copied the figure at their own pace. In this study, we followed the scoring system of Meyers and Meyers, which generates a combined score of accuracy and placement to assess visual-spatial grapho-motor skills. Raw scores (maximum 36) are transformed into standard scores. The higher the score, the better the performance. Acceptable validity (convergent and discriminant) and reliability (test-retest and inter-rater) measures of the RCFT were reported by the authors (Meyers & Meyers, 1995).

2.2.7. The Adolescents and Adults Coordination Questionnaire (AAC-Q; Tal-Saban, Ornoy, Grotto, & Parush, 2012)

The AAC-Q is a valid and standardized screening tool for individuals aged 16–30 years old. It is a self-report questionnaire which includes 12 items relating to coordination problems in daily activities, with higher scores (on a 1–5 Likert scale) indicating worse functioning. The AAC-Q has high internal consistency, construct validity, and test-retest reliability (Tal-Saban et al., 2012). In this study we used only two items representing fine- and gross-motor-related daily functions (e.g., *I have difficulty with physical activities such as riding a bike, sports activities, dancing; I have difficulties with fine motor daily activities requiring coordinated use of both hands, such as fastening, cutting, playing a musical instrument*).

2.3. Procedure

After receiving approval from the University's ethics review committee, we posted notices on the campus bulletin boards and at the Units for Diagnosis and Support for Students with Learning Disabilities, inviting students to participate in the study. Students who contacted us were invited to the Laboratory, received a detailed explanation of the study, and were asked to sign an informed consent form. Next, students were asked to fill out the background questionnaire and to perform the entire test battery. Testing was administered by a certified clinician with expertise in the area of learning disabilities, ADHD, and DCD. Testing time was approximately 2 h. Students received payment for participating in the study. After analyzing the data, students who were not found to be eligible were excluded.

2.4. Data analysis

Statistical analyses were performed using IBM SPSS statistical software (Version 20; IBM Corp., Armonk, NY). Descriptive statistics were employed to describe the study sample and the participants' performance. Normal distribution tests (one-sample Kolmogorov-Smirnov) showed that while handwriting speed was normally distributed, legibility was skewed. Therefore, analyses related to legibility were performed using non-parametric tests. Gender differences in handwriting speed and legibility were examined using t tests and Mann-Whitney tests, respectively. To compare the study groups with respect to their motor performance, separate ANOVA or Kruskal-Wallis tests were performed. Pearson or Spearman analyses were carried out to examine the relationship between motor functions in handwriting and motor-related daily functions. Finally, logistic regression was used to examine which motor functions contributed to the classification of students as having dysgraphia or as NDD.

3. Results

3.1. Sample description

Originally, the sample included 34 NDD students and 55 students with dysgraphia who met the study criteria. Recognizing the heterogeneity of the students with dysgraphia, we examined the distribution of their handwriting difficulties and found that they

Table 1
Means, standard deviation and comparison of study group on handwriting performance.

	Dysgraphia				Typically Developing			
	Only Legibility (n = 38)		Both[1] (n = 10)		(n = 34)			
Speed	*M*	*SD*	*M*	*SD*	*M*	*SD*	*F*	η_p^2
Copying	119.74	22.70	77.28	9.16	130.45	16.90	24.42***	.39
Dictation	154.26	19.47	124.30	15.88	161.33	5.76	28.37***	.42

	Dysgraphia				Typically Developing		
	Only Legibility (n = 38)		Both[1] (n = 10)		(n = 34)		
Legibility[2]	Median	IQR	Median	IQR	Median	IQR	χ^2
Copying	8.24	11.70	6.71	10.90	.45	1.86	51.10***
dictation	14.43	12.56	14.47	31.67	.98	3.04	55.55***

Note. [1]Both – Poor legibility and speed; [2]Higher scores indicate lower the legibility***$p < .001$.

comprised three subgroups: poor legibility, n = 38 (42.7%); slow handwriting, n = 7 (7.9%); and both difficulties, n = 10 (11.2%). Due to the small number of students with only speed difficulties, we did not include them in the study. Thus, the final sample consisted of three groups (N = 82): (a) 34 NDD students (M_{age} = 24.94, SD = 2.7), of whom 28 (82.4%) were males and 25 (73.5%) were right-handed; (b) 38 students with dysgraphia expressed in poor legibility (henceforth, the Legibility subgroup; M_{age} = 24.42, SD = 2.8), of whom 29 (76.3%) were males and 34 (89.5%) were right-handed; and (c) 10 students with dysgraphia expressed in both poor legibility and speed (henceforth, the Both subgroup; M_{age} = 24.3, SD = 1.9), of whom 9 (90%) were males and 7 (70%) were right-handed. The distribution of students with ADHD in the two dysgraphia groups, as reported by the students and supported by the ASRS (Kessler et al., 2005), was similar: 16% and 19%, respectively. Most students were first-year students (78.7% and 61.8%, respectively) studying in various areas (e.g., law, medicine, social sciences, humanities).

3.2. Group differences in handwriting performance

First, to examine possible confounding differences, we compared genders in handwriting speed and legibility. No significant differences ($p > .05$) were found for the copying and dictation tasks. Therefore, analyses were performed across genders. Similarly, within the group of students with dysgraphia, there were no significant differences ($p > .05$) in handwriting speed and legibility between those with and without ADHD. Descriptive statistics and comparisons of the handwriting performance of the study groups are described in Table 1. As can be seen in the Table, the groups significantly differed with respect to their handwriting performance. As expected, the TD group scored significantly higher on the two measures in both tasks.

3.3. Group differences in motor and daily functions

Next, we compared the three groups with respect to their motor functions, using separate ANOVAs. As can be seen in Table 2, there was a significant group effect in all the motor measures. Post hoc multiple comparisons with Bonferroni correction showed that the difference between the groups in the motor measures varied according to the motor functions. The NDD students performed significantly better than the two subgroups of students with dysgraphia on finger dexterity (the Purdue test). In visual-motor spatial

Table 2
Means, standard deviation and comparisons of study group on motor functions.

	Dysgraphia				Typically Developing				
	Legibility (A) n = 38		Both[1] (B) n = 10		(C) n = 34				
	M	*SD*	*M*	*SD*	*M*	*SD*	*F*	η_p^2	Group differences[4]
Purdue[2]	14.00	2.27	13.22	1.92	15.59	1.89	7.33***	.16	C > A, B**
RCFT[3]	29.13	4.34	29.95	3.72	32.47	2.81	4.51*	.13	C > A **
Finger Succession	7.14	2.16	10.54	6.95	5.60	1.93	10.22***	.21	A, C > B**

Notes: [1]Both – Poor legibility and speed; [2]Purdue, dominant hand task; [3]Rey Complex Figure Test and Recognition Trial (copying task); [4]Post hoc multiple comparisons with Bonferroni correction.
* $p < .05$.
** $p < .01$.
*** $p < .001$.

Table 3
Means, standard deviation and comparisons of study group on motor-related daily functions.

	Dysgraphia				Typically Developing			
	Legibility (A) $n = 38$		Both[1] (B) $n = 10$		(C) $n = 34$			
	Medium	*IQR*	*Medium*	*IQR*	*Medium*	*IQR*	χ^2	Group differences
Daily Functions								
Fine Motor[2]	3	3	3	3	5	5	23.42[(a)]**	C > A, B **
Gross Motor[2]	4.5	2	4	2	5	5	14.48[(a)]**	C > A, B **

Notes: [1]Both – Poor legibility and speed; [2]Modified Adolescents and Adults Coordination Questionnaire.
*$p < .05$; **$p < .01$; ***$p < .001$.

organization (RCFT), the TD students also scored higher than the Legibility subgroup, but not higher than the Both subgroup. In contrast, the Legibility subgroup and the TD students performed significantly better in sequential fine-motor skills than the Both subgroup (the Finger Succession test is timed). In comparing the groups with respect to their motor-related daily functions, using the Mann-Whitney test (Table 3), we found a group effect on both fine- and gross-motor-related daily functions. The NDD students reported functioning significantly better than the two subgroups with dysgraphia, but the two subgroups with dysgraphia did not significantly differ from each other ($p > .05$).

3.4. Correlations between motor functions, motor-related daily functions and handwriting

Due to the fact that the students in the two subgroups of dysgraphia did not significantly differ with respect to their motor performance in most tasks, we pooled their data together for subsequent analyses. Pearson (for speed) and Spearman (for legibility) analyses were carried out to examine the relationship between motor functions, motor-related daily functions, and handwriting performance. The results (Table 4) indicated that the accuracy of copying a complex design (RCFT) had a significant ($p < .05$) low negative correlation with handwriting speed, and a significant positive correlation with legibility. That is, the more accurately the students copied the design, the slower and more legibly they wrote. In addition, we found a significant ($p < .05$) low negative correlation between fine-motor-related daily functions and handwriting legibility. In other words, better fine-motor daily functions were related to good legibility. No other correlations were noted.

3.5. Factors predicting dysgraphia

Finally, we conducted logistic regression analysis to examine which motor functions and motor-related daily functions contributed to the classification of students as having dysgraphia or as NDD. Results indicated that taken together, the different motor functions explained 62.9% of the variance ($R^2 = .629$, $\chi^2 = 34.62$, $df = 5$, $p < .001$) and correctly classified 90% of the students into the handwriting performance groups. However, as can be seen in Table 5, only copying the design (RCFT) and fine-motor-related daily activities significantly contributed to the fit of the model ($B = -.296$, $SE = .12$, $p = .013$ and $B = -1.678$, $SE = .649$, $p = .01$, respectively).

4. Discussion

Most of the research on dysgraphia has focused on the pediatric population, with few studies targeting higher education students in general, and their motor skills or motor-related daily functions in particular. The results of this study showed significant differences between the higher education students with dysgraphia and those without any known developmental disorder in most motor skills

Table 4
Correlations between motor functions, motor-related daily functions and handwriting skills among students with dysgraphia ($n = 48$).

	Motor Functions			Motor-Related Daily Functions[4]	
	Purdue[1]	RCFT[2]	Finger Succession[3]	Fine-Motor	Gross-Motor
Handwriting					
Speed	.224	−.305*	−.224	.008	.164
Legibility	.077	.261*	-.213	−.258*	.052

Note. Correlations with handwriting speed were performed using Pearson correlations.
Correlations with legibility were performed using Spearman Correlations.
[1] Purdue, dominant hand task.
[2] Rey Complex Figure Test and Recognition Trial.
[3] in seconds.
[4] Modified Adolescents and Adults Coordination Questionnaire.

Table 5
Logistic regression predicting affiliation to handwriting performance group (N = 82).

Variable	*B*	*SE*	*Expβ*	*Wald*	*df*	95% *CI*
Purdue[1]	−.173	.229	.84	.57	1	.54-1.32
RCFT[2]	−.296	.120	.74	6.12*	1	.59-.94
Finger Succession[3]	.260	.217	1.30	1.44	1	.85-1.99
Daily Functions						
Fine Motor[4]	−1.678	.649	.19	6.68*	1	.05-.67
Gross Motor[4]	−.577	.42	.56	1.87	1	.25-1.29

Note. [1]Purdue, dominant hand task; [2]Rey Complex Figure Test and Recognition Trial; [3]in seconds; [4]Modified Adolescents and Adults Coordination Questionnaire.

and motor-related daily functions. These results suggest that there are students with specific learning disabilities who continue to have handwriting difficulties during their higher education studies, accompanied by difficulties in motor skills as well as motor-related daily functions.

Specifically, the results showed that the students with dysgraphia scored lower on visual-spatial grapho-motor skills than their without any known developmental disorder peers, and that this skill uniquely contributed to the prediction of handwriting ability group. These results contradict studies that *did not* find a correlation between visual-motor integration and handwriting skills (Goyen & Duff, 2005; Prunty et al., 2016). Perhaps the difference in the results can be explained by the figure we used in the RCFT test (Meyers & Meyers, 1995), as opposed to the designs in the Developmental Test of Visual-Motor Integration (Beery, Beery, & Buktenica, 2010) used in the above studies; the former are more complex, requiring higher visual-spatial organization skills similar to those necessary for handwriting. On the other hand, our results coincided with the findings by Brossard-Racine et al. (2011), 2015) as well as Graham et al. (2006), showing that visual-motor integration is an important predictor of handwriting legibility among students with and without ADHD.

It appears that the relationship between visual-motor integration and handwriting legibility, especially among older writers, is not sufficiently understood. Studies (Palmis et al., 2017) have shown that at the initial stages, handwriting is not automatic and requires processes similar to copying designs, including conscious sequential and controlled motor movement, while considering spatial codes and relying on visual feedback motor control. As students become more proficient (automatic) handwriters, the processes required for drawing shapes and handwriting diverge, and the handwriting process requires less involvement of the visual system.

This may raise the question: Why did we find a relationship among the higher education students with dysgraphia between visual-spatial grapho-motor skills and handwriting performance? The study by Richards et al. (2009) may shed light on this issue. In their study among 11-year-old children (an age level where handwriting is expected to reach automaticity), they asked participants to write newly taught pseudo-letters and highly practiced letters. Their results showed that similar to drawing (Palmis et al., 2017), the poorer writers showed more extensive brain activation (less efficient writing) than the better writers, specifically over-activation of the visual system. This may explain the relationship between visual-motor integration and handwriting skills among students with dysgraphia. However, this hypothesis should be treated with caution because the data is limited.

Our results also showed that the students with dysgraphia scored significantly lower than the NDD students in motor skills requiring sequential fine-motor movements, as well as finger speed and dexterity. These results are congruent with previous studies showing that children with dysgraphia had lower fine-motor skills, compared to NDD children (Klein et al., 2011; Nicolson & Fawcett, 2011; Prunty & Barnett, 2017; Smits-Engelsman & Van Galen, 1997).

Interestingly, neither measure of motor skills (PPT or Finger Succession) showed a significant correlation with handwriting performance. In contrast, fine-motor-related daily skills did have a low significant correlation with handwriting legibility, uniquely contributing to predicting students with and without dysgraphia. Perhaps these results suggest that, similar to handwriting, fine-motor daily functions such as fastening buttons, cutting, or playing a musical instrument are more complex than placing pegs in a pegboard; therefore, for young adults these daily functions more effectively tap the skills required for handwriting. Furthermore, these results indicate that among students with dysgraphia, the difficulties in motor skills and motor-related daily functions common in early childhood persist into young adulthood, along with the problems with handwriting.

It is likewise interesting to note that the gross-motor-related daily functions of the students in the two dysgraphia subgroups were significantly lower than those of the NDD students. This finding is congruent with previous studies showing that students with DCD have handwriting difficulties (Barnett et al., 2011; Blank et al., 2019; Prunty & Barnett, 2017; Wilson et al., 2017). However, these functions did not significantly predict students' handwriting abilities. These results are somewhat surprising and contradict earlier findings showing that children with dysgraphia scored significantly lower on a motor coordination test measuring both fine- and gross-motor functions (Prunty & Barnett, 2017). However, the researchers in that study did not measure gross-motor skills alone; in addition, the study focused on children rather than young adults. Therefore, future studies should examine gross-motor functions of students with dysgraphia as compared to those of NDD students.

There are a number of limitations to consider in this research. First, the study sample was limited, and the number of students whose handwriting difficulties were expressed in slow handwriting only was too small to include them. This study should be replicated with a larger sample size, as well as including students from different countries and languages, so as to validate these initial results. Second, the behavioral measures of this study examined only fine-motor skills. Future studies should include measures of gross-motor functions as well. Third, in this study the students with ADHD performed the tests under the influence of medication.

This may have confounded the results relating to their basic handwriting and motor performance, because the medication has been found to improve handwriting performance in this population (Brossard-Racine et al., 2015). Future studies on this topic should test this population without medication. Finally, the students with dysgraphia had one or more accompanying difficulties, including reading, written expression, and ADHD. Several may have also had DCD but did not report it as a diagnosis from childhood. Therefore, their varying handwriting performance and motor deficits may also have been related to the co-occurring disorders. Future studies should examine the handwriting performance of these groups separately, as well as their motor skills and motor-related daily functions.

5. Conclusion and clinical implications

This study examined the motor skills and motor-related daily functions of higher education students with dysgraphia, compared to NDD students. To the best of our knowledge, this is one of the first studies investigating this topic in this age group. The results of this study increase our knowledge of the links between motor functions and handwriting disorders, as well as the motor-related daily functions of this population. Furthermore, our findings showed that similar to handwriting, the motor difficulties of students with dysgraphia and their impact on daily functions do not disappear with age but continue into adulthood. This suggests that higher education students with dysgraphia may continue to require services and accommodations throughout their academic career, not only with regard to their academic studies but also in their motor-related daily functions in occupational areas such as self-care, work, or leisure.

References

Abbott, R. D., & Berninger, V. W. (1993). Structural equation modeling of relationships among developmental skills and writing skills in primary- and intermediate-grade writers. *Journal of Educational Psychology, 85*(3), 478–508.

American Psychiatric Association (1994). *Diagnostic and statistical manual of mental disorders* (4th ed). Washington, DC: Author.

American Psychiatric Association (2013). *Diagnostic and statistical manual of mental disorders – DSM-5®*. Washington, DC: American Psychiatric Association.

Barnett, A. L., Hill, E. L., Kirby, A., & Sugden, D. A. (2015). Adaptation and extension of the european recommendations (EACD) on developmental coordination disorder (DCD) for the UK context. *Physical & Occupational Therapy in Pediatrics, 35*(2), 103–115. https://doi.org/10.3109/01942638.2014.957430.

Barnett, A. L., Henderson, S. E., Scheib, B., & Schulz, J. (2011). Handwriting difficulties and their assessment in young adults with DCD: Extension of the DASH for 17- to 25-year-olds. *Journal of Adult Development, 18*(3), 114–121. https://link.springer.com/content/pdf/10.1007%2Fs10804-011-9121-3.pdf.

Barnett, A. L., Henderson, S. E., Scheib, B., & Schulz, J. (2009). *Development and standardization of a new handwriting speed test: The detailed assessment of speed of handwriting. BJEP monograph series II, number 6-teaching and learning writing, Vol. 137*, London: British Psychological Society137–157. https://doi.org/10.1348/000709909X421937 No. 157.

Beery, K., Beery, N., & Buktenica, N. (2010). *The beery-buktenica developmental test of visual-motor integration (manual)*. Bloomington, MN: Pearson Assessments.

Berninger, V. W., Richards, T. L., & Abbott, R. D. (2015). Differential diagnosis of dysgraphia, dyslexia, and OWL LD: Behavioral and neuroimaging evidence. *Reading and Writing: An Interdisciplinary Journal, 28*(8), 1119–1153. https://doi.org/10.1007/s11145-015-9565-0.

Berninger, V., & Richards, T. (2010). Inter-relationships among behavioral markers, genes,brain and treatment in dyslexia and dysgraphia. *Future Neurology, 5*(4), 597–617. https://doi.org/10.2217/fnl.10.22.

Berninger, V. W., & Rutberg, J. (1992). Relationship of finger function to beginning writing: Application to diagnosis of writing disabilities. *Developmental Medicine and Child Neurology, 34*(3), 198–215.

Blank, R., Barnett, A. L., Cairney, J., Green, D., Kirby, A., Polatajko, H., et al. (2019). International clinical practice recommendations on the definition, diagnosis, assessment, intervention, and psychosocial aspects of developmental coordination disorder. *Developmental Medicine and Child Neurology, 61*(3), 242–285. https://doi.org/10.1111/dmcn.14132.

Bo, J., & Lee, C. M. (2013). Motor skill learning in children with developmental coordination disorder. *Research in Developmental Disabilities, 34*(6), 2047–2055. https://doi.org/10.1016/j.ridd.2013.03.012.

Brossard-Racine, M., Majnemer, A., Shevell, M., Snider, L., & Bélanger, S. A. (2011). Handwriting capacity in children newly diagnosed with attention deficit hyperactivity disorder. *Research in Developmental Disabilities, 32*(6), 2927–2934. https://doi.org/10.1016/j.ridd.2011.05.010.

Brossard-Racine, M., Shevell, M., Snider, L., Bélanger, S. A., Julien, M., & Majnemer, A. (2015). Persistent handwriting difficulties in children with ADHD after treatment with stimulant medication. *Journal of Attention Disorders, 19*(7), 620–629. https://doi.org/10.1177/1087054712461936.

Brown, T., & Link, J. (2015). The association between measures of visual perception, visual-motor integration, and in-hand manipulation skills of school-age children and their manuscript handwriting speed. *The British Journal of Occupational Therapy, 79*(3), 163–171. https://doi.org/10.1177/0308022615600179.

Denckla, M. B. (1973). Development of speed in repetitive and successive finger-movements in normal children. *Developmental Medicine and Child Neurology, 15*(5), 635–645.

Duiser, I. H., van der Kamp, J., Ledebt, A., & Savelsbergh, G. J. (2013). Relationship between the quality of children's handwriting and the Beery Buktenica developmental test of visuomotor integration after one year of writing tuition. *Australian Occupational Therapy Journal, 61*(2), 76–82. https://doi.org/10.1111/1440-1630.12064.

Engel-Yeger, B., Nagauker-Yanuv, L., & Rosenblum, S. (2009). Handwriting performance, self-reports, and perceived self-efficacy among children with dysgraphia. *American Journal of Occupational Therapy, 63*(2), 182–192.

Gagnon-Roy, M., Jasmin, E., & Camden, C. (2016). Social participation and interventions supporting teenagers and young adults living with developmental coordination disorder (DCD): Results from a scoping review. *Child: Care, Health and Development, 42*, 840–851. https://doi.org/10.1111/cch.12389.

Goyen, T. A., & Duff, S. (2005). Discriminant validity of the Developmental Test of Visual–Motor Integration in relation to children with handwriting dysfunction. *Australian Occupational Therapy Journal, 52*(2), 109–115.

Graham, S., Fishman, E. J., Reid, R., & Hebert, M. (2016). Writing characteristics of students with attention deficit hyperactive disorder: A meta-analysis. *Learning Disabilities Research and Practice, 31*(2), 75–89. https://doi.org/10.1111/ldrp.12099.

Graham, S., & Harris, K. R. (2013). Common core state standards, writing, and students with LD: Recommendations. *Learning Disabilities Research and Practice, 28*(1), 28–37. https://doi.org/10.1111/ldrp.12004.

Graham, S., Struck, M., Santoro, J., & Berninger, V. W. (2006). Dimensions of good and poor handwriting legibility in first and second graders: Motor programs, visual–Spatial arrangement, and letter formation parameter setting. *Developmental Neuropsychology, 29*(1), 43–60. https://doi.org/10.1207/s15326942dn2901_4.

Kaiser, M. L., Albaret, J. M., & Doudin, P. A. (2009). Relationship between visual-motor integration, eye-hand coordination, and quality of handwriting. *Journal of Occupational Therapy Schools & Early Intervention, 2*(2), 87–95. https://doi.org/10.1080/19411240903146228.

Kaiser, M. L., Schoemaker, M. M., Albaret, J. M., & Geuze, R. H. (2015). What is the evidence of impaired motor skills and motor control among children with attention deficit hyperactivity disorder (ADHD)? Systematic review of the literature. *Research in Developmental Disabilities, 36*, 338–357. https://doi.org/10.1016/j.ridd.2014.09.023.

Kessler, R. C., Adler, L., Ames, M., Demler, O., Faraone, S., Hiripi, E. V. A., et al. (2005). The World Health Organization Adult ADHD Self-Report Scale (ASRS): A short

screening scale for use in the general population. *Psychological Medicine, 35*(2), 245–256.
Kirby, A., Edwards, L., Sugden, D., & Rosenblum, S. (2010). The development and standardization of the adult developmental co-ordination disorders/dyspraxia checklist (ADC). *Research in Developmental Disabilities, 31*(1), 131–139. https://doi.org/10.1016/j.ridd.2009.08.010.
Klein, S., Guiltner, V., Sollereder, P., & Cui, Y. (2011). Relationships between fine-motor, visual-motor, and visual perception scores and handwriting legibility and speed. *Physical & Occupational Therapy in Pediatrics, 31*(1), 103–114. https://doi.org/10.3109/01942638.2010.541753.
McCloskey, M., & Rapp, B. (2017). Developmental dysgraphia: An overview and framework for research. *Cognitive Neuropsychology, 34*(3-4), 65–82. https://doi.org/10.1080/02643294.2017.1369016.
Meyers, J. E., & Meyers, K. R. (1995). *Rey complex figure test and recognition trial: RCFT: Professional manual.* Lutz, FL: PAR.
Murphy, K. R., & Adler, L. A. (2004). Assessing attention-deficit/hyperactivity disorder in adults: Focus on rating scales. *The Journal of Clinical Psychiatry, 65*, 12–17.
Nicolson, R. I., & Fawcett, A. J. (2011). Dyslexia, dysgraphia, procedural learning and the cerebellum. *Cortex, 47*(1), 117–127. https://doi.org/10.1016/j.cortex.2009.08.016.
Palmis, S., Danna, J., Velay, J. L., & Longcamp, M. (2017). Motor control of handwriting in the developing brain: A review. *Cognitive Neuropsychology, 34*(3-4), 187–204. https://doi.org/10.1080/02643294.2017.1367654.
Parush, S., Levanon-Erez, N., & Weintraub, N. (1998). Ergonomic factors influencing handwriting performance. *Work, 11*(3), 295–305.
Parush, S., Lifshitz, N., Yochman, A., & Weintraub, N. (2010). Relationships between handwriting components and underlying perceptual-motor functions among students during copying and dictation tasks. *OTJR Occupation Participation Health, 30*(1), 39–48 https://doi.org/10.3928%2F15394492-20091214-06.
Peverly, S. T., Garner, J. K., & Vekaria, P. C. (2014). Both handwriting speed and selective attention are important to lecture note-taking. *Reading and Writing: An Interdisciplinary Journal, 27*(1), 1–30. https://link.springer.com/article/10.1007/s11145-013-9431-x.
Prunty, M., & Barnett, A. L. (2017). Understanding handwriting difficulties: A comparison of children with and without motor impairment. *Cognitive Neuropsychology, 34*(3-4), 205–218. https://doi.org/10.1080/02643294.2017.1376630.
Prunty, M. M., Barnett, A. L., Wilmut, K., & Plumb, M. S. (2014). An examination of writing pauses in the handwriting of children with developmental coordination disorder. *Research in Developmental Disabilities, 35*(11), 2894–2905. https://doi.org/10.1016/j.ridd.2014.07.033.
Prunty, M., Barnett, A. L., Wilmut, K., & Plumb, M. (2016). Visual perceptual and handwriting skills in children with developmental coordination disorder. *Human Movement Science, 49*, 54–65. https://doi.org/10.1016/j.humov.2016.06.003.
Richards, T. L., Berninger, V. W., Stock, P., Altemeier, L., Trivedi, P., & Maravilla, K. (2009). fMRI imaging sequential-finger movement activation differentiating good and poor writers. *Journal of Clinical and Experimental Neuropsychology, 31*(8), 967–983. https://doi.org/10.1080/13803390902780201.
Rosenblum, S., Margieh, J. A., & Engel-Yeger, B. (2013). Handwriting features of children with developmental coordination disorder: Results of triangular evaluation. *Research in Developmental Disabilities, 34*(11), 4134–4141. https://doi.org/10.1016/j.ridd.2013.08.009.
Smits-Engelsman, B. C., & Van Galen, G. P. (1997). Dysgraphia in children: Lasting psychomotor deficiency or transient developmental delay? *Journal of Experimental Child Psychology, 67*(2), 164–184.
Tal-Saban, M., Ornoy, A., Grotto, I., & Parush, S. (2012). Adolescents and adults' coordination questionnaire: Development and psychometric properties. *American Journal of Occupational Therapy, 66*(4), 406–413. https://doi.org/10.5014/ajot.2012.003251.
Tal-Saban, M., Ornoy, A., & Parush, S. (2014). Executive function and attention in young adults with and without developmental coordination disorder: A comparative study. *Research in Developmental Disabilities, 35*(11), 2644–2650. https://doi.org/10.1016/j.ridd.2014.07.002.
Tal-Saban, M., Ornoy, A., & Parush, S. (2016). Participation and quality of life of young adults with developmental coordination disorder: A longitudinal study. *American Journal of Occupational Therapy, 70*(4_Supplement_1), https://doi.org/10.5014/ajot.2016.70S1-PO4108 1-7011505142p1.
Tiffin, J. (1960). *Instructions and normative data for model 32020 Purdue Pegboard.* Chicago, IL: Science Research Associates.
Ustun, B., Adler, L. A., Rudin, C., Faraone, S. V., Spencer, T. J., Berglund, P., et al. (2017). The World Health Organization adult attention-deficit/hyperactivity disorder self-report screening scale for DSM-5. *JAMA Psychiatry, 74*(5), 520–526. https://doi.org/10.1001/jamapsychiatry.2017.0298.
Van der Linde, B. W., Van Netten, J. J., Otten, E., Postema, K., Geuze, R. H., & Schoemaker, M. M. (2015). A systematic review of instruments for assessment of capacity in activities of daily living in children with developmental co-ordination disorder. *Child: Care, Health and Development, 41*(1), 23–34. https://doi.org/10.1111/cch.12124.
Van Galen, G. P. (1991). Handwriting: Issues for a psychomotor theory. *Human Movement Science, 10*(2-3), 165–191.
Weigelt-Marom, H. W., & Weintraub, N. (2015). The effect of a touch-typing program on keyboarding skills of higher education students with and without learning disabilities. *Research in Developmental Disabilities, 47*, 208–217. https://doi.org/10.1016/j.ridd.2015.09.014.
Weintraub, N., & Graham, S. (2000). The contribution of gender, orthographic, finger function, and visual-motor processes to the prediction of handwriting status. *The Occupational Therapy Journal of Research, 20*(2), 121–140.
Weintraub, N., Gilmour-Grill, N., & Weiss, P. L. T. (2010). Relationship between handwriting and keyboarding performance among fast and slow adult keyboarders. *American Journal of Occupational Therapy, 64*(1), 123–132. https://doi.org/10.5014/ajot.64.1.123.
Weintraub, N., Israeli-Ovadia, A., Shoval, H., & Traub-Bar-Ilan, R. (2012). *The handwriting performance of post-secondary students evaluation (HaPPS).* Jerusalem, Israel: The School of Occupational Therapy of Hadassah and the Hebrew University.
Wilson, P. H., Smits-Engelsman, B., Caeyenberghs, K., Steenbergen, B., Sugden, D., Clark, J., et al. (2017). Cognitive and neuroimaging findings in developmental coordination disorder: New insights from a systematic review of recent research. *Developmental Medicine and Child Neurology, 59*(11), 1117–1129. https://doi.org/10.1111/dmcn.13530.
Yancosek, K. E., & Howell, D. (2009). A narrative review of dexterity assessments. *Journal of Hand Therapy, 22*(3), 258–270.
Zwicker, J. G., Suto, M., Harris, S. R., Vlasakova, N., & Missiuna, C. (2018). Developmental coordination disorder is more than a motor problem: Children describe the impact of daily struggles on their quality of life. *The British Journal of Occupational Therapy, 81*(2), 65–73 https://doi.org/10.1177%2F0308022617735046.