The Mental Effort Allocated in Handwriting Production among Adolescents with Executive Function Deficits

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Abstract. This study aimed to compare handwriting-product and -process measures between adolescents with executive function deficits (EFD) and controls and predict group membership. In a secondary analysis with 81 adolescents aged 10–18 years (41 characterized with daily function difficulties and EFD by parent-reported Behavioral Rating Inventory of Executive Function), participants copied 2 paragraphs onto a paper affixed to a digitizer for objective handwriting-process measures. Their written products were scored according to the Handwriting Legibility Scale, which assesses global legibility, overall effort to read the script, layout on page, letter formation, and text alterations. Significant group differences were found in Tasks 1 and 2 (effort, layout) and temporal-process measure (in-air, on-paper time), and Task 2 global legibility, letter formation, and pen-pressure components. Significant within-group differences were found for Tasks 1 and 2 velocity, in-air time, stroke weight, and height measures while the EFD group showed significant within-group differences for global legibility and Task 1 tilt. The discriminant-function analyses identified that product and process measures correctly classified 75% of the groups. Results suggest handwriting production is important to understanding deeper handwriting-product and -process measures. Combining handwriting-product and -process measures may reflect the mental-effort process, emphasizing the complexity of handwriting as a routine daily performance among adolescents with EFD.

1. Introduction

Handwriting, a complex everyday activity of forming letters, numbers, and characters, requires a combination of cognitive functions and fine and gross motor skills (Dinehart, 2015). Optimal control of spatial and temporal constraints to produce a legible trace as quickly as possible characterize skilled handwriting (Palmis et al., 2017). Everyday activities with simple or complex demands require allocating varying degrees of mental effort. While performing these activities, such as handwriting, individuals subjectively assess, implicitly or explicitly, how much mental effort they should allocate to accomplish the task. Mental effort refers to the capacity or resources allocated to accommodate the task demands (Paas & van Merriënboer, 1994). It is affected by task features, individual characteristics, and their interaction (Scheiter et al., 2020; Shenhav et al., 2017).

According to cognitive load theory (Sweller, 1998), mental effort is assumed to result mainly from data-driven processes (Baars et al., 2020; Scheiter et al., 2020). In a *data-driven process*, task demands are imposed on a person's cognitive resources: the more complex the task, the more the mental load is independent of the individual's characteristics. That is, an easy task requires less effort than would a more challenging task (Scheiter et al., 2020). Copy tasks are frequently required of students in the classroom. For instance, students copy sentences or rules from the board or write homework instructions to be completed (and inspected by parents) at home (Grabowski, 2010). When copying letters or words, children must not only control the fine movement and force of their fingers and hands, but also attend to relevant stimuli, retain the target to be copied in working memory, coordinate visual and manual movements, and integrate this perceptual and motor information with linguistic rules about orthographic structure. Coordinating all these elements when copying letters and words helps ensure the handwriting is fluent, automatic, and legible—key markers of skill mastery (Stevenson & Just, 2014).

It is already known that adolescents with executive function (EF) deficits (EFD) have trouble planning, monitoring, and especially, integrating all cognitive and motor components required for effective handwriting (Re & Cornoldi, 2010). Difficulties in these EF components may be the mechanisms underlying their challenges and deficient daily functions, including handwriting performance (Cramm et al., 2016; Mann & Snover, 2015). Therefore, this study aims to examine in depth the differences between adolescents with and without EFD in a complex handwriting task (two copying tasks, one after the other) and to understand the differences in the global product and specific objective process measures throughout subjective (Handwriting Legibility Scale; HLS) and objective (Computerized Penmanship Evaluation Tool; ComPET) measures to reveal the role of EFD in achieving mental-effort allocation in handwriting tasks. This analysis has two main research hypotheses:
(1) Significant differences will be found between adolescents with EFD and those with typical development (TD) across and within two handwriting copying tasks in product measure as assessed by the handwriting legibility as scored by the HLS and in process features as measured by the ComPET and HLS components; and

(2) Specific handwriting-product and -process measures will best discriminate between adolescents with EFD and those with TD.

2. Methods

2.1. Participants

Eighty-one adolescents aged 10 to 18 years were included in the study; 41 with EFD who experience difficulties in their daily functioning according to parents' reports in the Behavioral Rating Inventory of Executive Function (BRIEF) scores of 65 or above, constituted the research group. The research group included 29 (70.7%) boys and 12 (29.3%) girls with a mean age of 11.88 ± 1.08 years. Forty adolescents with TD matched by age and gender comprised the control group. There were no significant group differences for demographic measures. Adolescents with known neurotic, emotional, or autistic disorders, physical disabilities, or neurological diseases were excluded from the study.

2.2. Instruments

2.2.1. Participant Selection (Executive Function Profile): BRIEF

The BRIEF parent-report (Gioia et al., 2000) consists of 86 items designed to evaluate EF control levels. Parents rate their child's behavior on a three-point Likert scale of 1 (*never*), 2 (*sometimes*), or 3 (*often*). Eight scales are obtained in two indexes: a metacognition index containing five subscales of initiate, working memory, plan/organize, organization of materials, and monitor; a behavioral regulation index containing three subscales of inhibit, shift, and emotional control. *T* scores at or above 65 are considered clinically significant for dysexecutive functions. Mean internal consistency ranges from .82 to .98. Test–retest correlations range from .72 to .84.

2.2.2. Handwriting Product: HLS

The HLS (Barnett et al., 2018) was designed to examine performance on five components of legibility: global legibility (overall readability of the text on first reading), effort required to read the script, layout on the page, letter formation, and writing alterations (attempts to rectify written work). Each component is summed to a total score for legibility. Total scores range from 5 to 25, with higher scores reflecting poorer legibility.

2.2.3. Handwriting Process: ComPET

The ComPET (previously, POET; Rosenblum et al., 2003) was used to assess participants' handwriting process measures. Participants copied two paragraphs onto a sheet of paper affixed to a Wacom Intuos II x-y digitizing tablet (404 x 306 x 10 mm) while using a wireless electronic pen with a pressure-sensitive tip (Model GP-110). This part of the ComPET enables receipt of the exact time of task performance in s, mean pressure applied towards the writing surface in nonscaled units from 0 to 1024, and mean stroke height reflecting the height of letters in mm.

2.3. Procedure

The study was approved by the Ethics Committee of the University of Haifa, and all parents and adolescents signed informed consent forms for participation in the study. Participants copied 2 paragraphs onto a paper affixed to a digitizer for objective handwriting-process measures. The tasks were performed in Hebrew, which progresses from right to left. The first task included 46 words and the second task included 274 words.

3. Results

3.1. Differences Between Groups (Product and Process) in the Two Copy Tasks

As expected, significant differences were found between the groups in the HLS components. Results of the MANOVAs (Table 1) demonstrated that adolescents with TD performed significantly better than did adolescents with EFD in Task 1, $F(5,75) = 3.54$, $p = 0.06$, $\eta^2 = 0.19$, and in Task 2, $F(5,75) = 2.86$, $p = 0.0$, $\eta^2 = 0.16$. These results present significant differences between groups in Task 1 for effort required and layout on the page and in Task 2 for global legibility.

Table 1. Between-Group Differences Adolescents in Handwriting Legibility Scored by the HLS in Two Copy Tasks

HLS component	Task 1					Task 2				
	EFD (n = 41)	TD (n = 40)	F (1,79)	η^2	p	EFD (n = 41)	TD (n = 40)	F (1,79)	η^2	p
	M (*SD*)					*M* (*SD*)				
Global legibility	1.71 (0.78)	1.58 (0.67)	.660	.00	.420	1.98 (0.82)	1.58 (0.67)	5.74	.07	.020
Effort required	2.27 (0.77)	1.77 (0.77)	8.73	.09	.005	2.32 (0.88)	1.78 (0.77)	8.73	.09	.004
Layout on page	2.44 (1.12)	1.68 (0.76)	12.81	.14	.001	2.32 (1.01)	1.67 (0.76)	10.36	.11	.002
Letter formation	2.07 (0.79)	1.80 (0.65)	2.90	.03	.090	2.15 (0.73)	1.80 (0.65)	5.11	.06	.026
Alterations	2.15 (0.82)	1.85 (0.74)	2.91	.03	.090	2.00 (0.81)	1.88 (0.72)	0.54	.00	.460

Note. EFD, executive function deficit; HLS, Handwriting Legibility Scale; TD, typical development.

As expected, significant differences were found between the groups in the temporal components of the ComPET in Task 1, $F(1,79) = 10.91$, $p = 0.01$, $\eta^2 = 0.12$, and in Task 2, $F(1,79) = 6.49$, $p = 0.01$, $\eta^2 = 0.08$. Moreover, in Task 2 significant between-group differences were found in pen pressure, $F(1,79) = 6.54$, $p = 0.01$, $\eta^2 = 0.08$. No significant differences were found for the other handwriting process measures (velocity, azimuth, tilt, stroke weight and height).

3.2. Differences Within Groups (Product and Process) in the Two Copy Tasks

Significant differences were found in the EFD group between Tasks 1 and 2 in HLS global legibility, $t(40) = -2.9$, $p = 0.06$, $d = 0.33$, and in alteration, $F(40) = 2.62$, $p = 0.01$, $d = 0.18$. No significant differences were found in the TD group for HLS components. Significant differences were found in the both groups between Tasks 1 and 2 in handwriting-process measures of velocity, stroke in-air, stroke weight and height (Table 2). Interestingly, in the EFD group, significant differences between Tasks 1 and 2 were found in the tilt component.

Table 2. Within-Group Differences for Two Copy Tasks: Handwriting Process Measures Scored by the ComPET

ComPET component	EFD Group (n = 41)					TD Group (n = 40)				
	Task 1	Task 2	*t*	*p*	*d*	Task 1	Task 2	*t*	*p*	*d*
	M (*SD*)					*M* (*SD*)				
Velocity	5.790 (1.910)	4.82 (1.58)	6.95	.000	.55	6.33 (1.62)	5.36 (1.20)	3.68	.001	.68
Pen pressure	470.192 (128.100)	456.91 (119.21)	1.26	.210	.11	519.76 (122.66)	523.36 (114.48)	-0.13	.900	.03
Pen Azimuth	101.020 (53.710)	100.67 (53.73)	0.33	.740	.00	98.47 (64.60)	98.28 (64.56)	0.02	.980	.00
Pen Tilt	61.950 (6.570)	60.41 (5.74)	3.49	.001	.25	61.91 (5.60)	61.35 (5.94)	0.46	.650	.09
Stroke time in-air	0.660 (0.350)	0.81 (0.45)	-4.92	.000	.37	0.44 (0.17)	0.53 (0.22)	-2.29	.030	.46
Stroke time on-paper	0.240 (0.090)	0.23 (0.11)	1.44	.160	.10	0.20 (0.06)	0.18 (0.03)	1.86	.070	.42
Stroke weight	0.390 (0.120)	0.33 (0.10)	6.44	.000	.54	0.37 (0.10)	0.32 (0.09)	2.57	.010	.52
Stroke height	0.730 (0.210)	0.58 (0.15)	7.86	.000	.82	0.67 (0.21)	0.52 (0.14)	3.61	.001	.84

Note. EFD, executive function deficit; ComPET, Computerized Penmanship Evaluation Tool; TD, typical development.

3.3. Predicting Group Classification by Product and Process Measures for Each Task

The discriminate function was found for group classification of participants in Task 1 ($\Lambda = .70$, $p < .01$) and Task 2 ($\Lambda = .68$, $p < .008$) analyses of the handwriting-product and -process measures. For Tasks 1 and 2, only four measures contributed considerably to group classifications. The variables providing the most significant contribution to group membership in Task 1 were *layout on the page* from the handwriting product–legibility (loading = .62) and *in-air* from the handwriting-process measures (loading = .57). The greatest contribution to group membership in Task 2 was *in-air* time from the handwriting-process measures (loading = .58) and *layout on the page* from the handwriting product–legibility (loading = .52). Table 3 presents values for all product and process measures. Based on these functions for Task 1, 76.5% of study participants were correctly classified into their respective groups (specifically, 68.3% of participants in the EFD group and 85% in the TD group). A Kappa value of .53 ($p < .001$) was calculated, demonstrating that group classification did not occur by chance. For Task 2, 76.5% of study participants were correctly classified into their respective groups (i.e., 75.6% of participants with EFD, and 77.5% in the TD group). A Kappa value of .53 ($p < .001$) was calculated, demonstrating that group classification did not occur by chance.

Table 3. Discriminant Function Analysis: Predictor Loading Value (Product and Process Measures)

Function	Task 1	Task 2
Layout on the page	.62	.52
In-air	.57	.58
Effort	.49	.48
On-paper	.44	.47

4. Discussion

This study's results reflect the complex picture of the neurofunctional expression of adolescents with EFD when performing daily tasks required from them at school. The significant differences between the two groups are expressed most meaningfully in Task 2 (*global legibility* for the product and *pen pressure* for the process). These findings align with the cognitive load theory and with a large body of literature from basic science. Prior studies argued that EF are the underlying mechanisms that enable or inhibit daily functioning in general (Fogel et al., 2019) and task performance specifically (Fogel et al., 2020).

Within each group, the task requirement (two tasks, one after the other) showed no significant differences; that is, as the type of task continues, both groups' global legibility decreases. Moreover, in the process measure, except for the tilt measure, there are similar differences between the groups. This means that although the objective measure changes similarly in both groups, there are still individual differences in the product. The pen tilt measure indicates mastery over the instrument/pen and hand movements related to space while producing letters on paper (Rosenblum, 2015). In the EFD group, the results indicate a decrease in the tilt component between Tasks 1 and 2. Because we have no information about the motor abilities of the adolescents in the EFD group, there may be two explanations for this finding that require further research. The EF are associated with motor difficulties, as the developmental coordination disorder literature already recognized (Rosenblum et al., 2014). The second explanation may relate to characteristics of adolescents with EFD expressed in low motivation and interest to perform complex and prolong tasks. This insight is especially important when thinking about how much mental effort children put into performing handwriting tasks at school and especially for those with challenges in EF.

The final analysis revealed two meaningful results: the handwriting's high ability to classify more than 75% to the original group and the high-loading combination of product and process components. Although the current study didn't assess actual mental effort directly, the results highlight how subjective and objective handwriting measures might reflect the mental effort allocated in handwriting production. To date, this is the first analysis that attempt to connects handwriting production to mental effort. Future research is needed to deepen these relationships and assess subjective and objective mental effort in more ways (e.g., participants' self-reports). Additionally, future studies should explore the tilt components and their relationship to EF to understand the implication for academic and nonacademic outcomes in adolescence. This study adds more evidence of handwriting as a mirror to daily functioning.

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