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The effects of protracted graphomotor tasks on tripod pinch strength and handwriting performance in children with dysgraphia

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Abstract
Purpose. To examine the impact of prolonged graphomotor tasks on tripod-pinch strength and on handwriting process and product measures of children with dysgraphia and typical peers.
Method. Participants were 51 children in third to fifth grades, divided into two groups: 23 children with dysgraphia and 28 typical peers, as determined by the Handwriting Proficiency Screening Questionnaire. The procedure included two sessions, with a 15-min break between sessions. In each session, the participants performed two tasks: the visual-motor control subtest of Bruininks-Oseretsky and a handwriting copying task, both performed on an electronic tablet as part of the Computerised Penmanship Evaluation Tool. Tripod pinch strength was evaluated before and after each session.
Results. Significantly lower tripod-pinch strength was found among children with dysgraphia in comparison to typically developed peers. This deterioration in tripod-pinch strength was associated with a significant deterioration in handwriting process and product measures along the protracted task.
Conclusions. Pinch force that is required for mastering the handwriting tool needs to be considered in the evaluation process of children with dysgraphia. Combining the pinch factor with an evaluation of handwriting's process and product may supply a better insight about the child's deficits and assist in focusing treatment objectives.

Keywords: Dysgraphia, graphomotor, children

Introduction
Handwriting was categorised by school-aged children as the ultimate work activity [1]. It is not surprising based on McHale and Cermak's [2] findings that 30–60% of children's school day is spent in the performance of fine motor tasks, consisting primarily of handwriting. Eklund [3] indicated that effective work performance produces a quality product through an efficient process.

Handwriting is a complex motor activity that represents the integration of linguistic, psychomotor, biomechanical, maturational, developmental and learning processes [4].

The previous research, which focussed on the kinematic aspects of handwriting, did not necessarily provide information on the unique kinetic relationships between the hand and pen [5]. Moreover, the inability to physically fit the necessary sensors into a natural grip setting, as used in writing activity, prevented the extension to kinetic handwriting research [6].

A non-efficient work of handwriting has been defined as dysgraphia [7]. The term dysgraphia has been used to specify a disorder of written expression of language in childhood [8]. The term refers to children who do not succeed in developing proficient handwriting. Hamstra-Bletz and Blote [9] defined dysgraphia as a disturbance or difficulty in the production of written language related to the mechanics of writing among children who are of at least average intelligence and who have not been identified as having any obvious neurological or perceptual-motor problems.

Non-effective work performance in the case of handwriting as a complex human skill may stem from several deficits, including limited muscle strength and fine motor skills as well as deficient perceptual-motor abilities [10,11]. Although clinicians mentioned muscle strength deficits as a possible cause for...
non-efficient handwriting, this point has not been studied yet with standardised measures [12]. Clinicians assumed that appropriate muscle strength required for efficient use of the pen or pencil to complete the work of performing graphomotor assignments [13,14].

Tripod pinch strength is required for varied every day activities as handwriting and drawing. These activities may be used for objectively measure muscle strength deficits. The ‘dynamic tripod’ refers to the force generated by the pulp of the thumb, the index finger and the middle finger [15] in the most common ways of holding a writing instrument [16,17] where the three fingers (thumb, index and middle finger) function together to hold the pen while the fourth and fifth fingers are leading the hand on the writing surface [18]. The force exerted by the three fingers must be adapted to the pen’s weight, acceleration, surface texture, contour and structure [19]. Previous literature that refers to the negative impacts of reduced force on motor performance [e.g. 20] raises the need to further study the impacts of force use on graphomotor performance, especially among children with motor impairments, as children with dysgraphia. Furthermore, this question needs to be studied during protracted writing task, in light of the findings of Dennis and Swinth [21], according to which longer task time was associated with decrease handwriting product legibility among school-aged children.

Until recently, minimal attention has been given to the question of handwriting mechanisms and efficiency of this kind of children’s work [22]. To the best of our knowledge, no study has assessed tripod pinch strength as a manifestation of pencil grip ability and handwriting performance especially in prolonged double performance conditions resembling the demands in class. No meaningful results have been found for the relationships between tripod pinch strength as a reflection of pencil grip ability and an indicator for muscle fatigue during graphomotor performance, and the quality, speed or efficacy of handwriting performance [13,21].

In the current study, children with dysgraphia and typically developing children were requested to perform prolonged tasks, which included two sessions of visual-motor and handwriting tasks, to imitate classroom conditions. Their tripod pinch strength was measured before and after each of the two sessions. The handwriting efficiency was measured by evaluation of the legibility of the writing product, as well as by computerised objective measures of the handwriting process.

It was hypothesised that (1) significant differences will be found between children with dysgraphia and typically developing (TD) peers before and after graphomotor task performance in their tripod strength, and their handwriting process and products measures. (2) Effects of protracted activities on graphomotor performance will be greater among the children with dysgraphia.

Methods

Participants

Participants were 51 children, including 23 children with dysgraphia and 28 TD peers, without dysgraphia, who study in the third to fifth grades in mainstream schools in Israel. Children were selected from the third grade and above as the target population as a result of research that indicates that by the time a child reaches this grade handwriting has become efficient, organised and readily available as a tool to facilitate the development of ideas [23,24]. Thus, children from the third grade whose handwriting lack these qualities are dealing with developmental dysgraphia. The two groups were determined in accordance with the cut-off score of the Handwriting Proficiency Screening Questionnaire (HPSQ) [25], which was completed by the children’s teachers. The study group consisted of 15 boys and 8 girls, with a mean age of 9.63 ± 0.86 years. The control group consisted of 13 boys and 15 girls, with a mean age of 9.43 ± 1.13 years. In both groups, four of the children were left handed.

Exclusion criteria included developmental delays, positive neurological findings, chronic diseases and syndromes, learning disabilities, vision impairments and treatment with medications that affect the functioning of the nervous system. These exclusion criteria were ascertained by parents report.

Instruments

Demographic questionnaire. This questionnaire was composed by the authors and included data on family socio-demographic status, child’s health status, medications, treatments and para-medical therapies.

The handwriting proficiency screening questionnaire [25]. The HPSQ is a 10-item questionnaire that was developed for use by teachers or clinicians to identify school-aged children with handwriting difficulties. The items are scored on a 5-point Likert scale, ranging from 0 = never to 4 = always, with higher scores indicating poorer performance. The final score is computed by summing the scores of all the 10 test items. The tool demonstrated good internal consistency (α = 0.90). Test–retest for the overall score revealed an ICC of 0.84 and inter-rater reliability of ICC = 0.92 for the overall questionnaire score, with
values of 0.64–0.91 for the individual items. Construct validity was also confirmed. Furthermore, results demonstrated that the questionnaire (HPSQ) significantly distinguishes between children with and without handwriting deficiencies. Moderate significant correlations ($r = 0.52–0.65$, $p < 0.001$) were found between the questionnaire score and scores on the Handwriting Hebrew Evaluation of the handwriting product and measures of the handwriting process (ComPET) (see [25] for further details).

**B & L pinch gauge (0-60 lb).** B & L pinch gauge was used to measure tripod strength measured as the palmar pinch force described in the standardised instructions [26]. The instrument was held by the examiner at the distal end to prevent dropping. The palmar pinch force was measured, while children were requested to press the instrument where thumb and fingers are on either side of the measurement surface – the thumb was placed beneath the pressure surface and both index and third fingers are placed above, similar to the natural writing position, according to the measurement standards [27]. Scores were read at the needle side of the red readout marker. The calibration of the instrument was tested periodically during the study. This posture was used because of its similarity to the tripod position used with the pen.

**Visual-motor control subtest of the Bruininks-Oseretsky Test of Motor Proficiency (BOTMP)** [28]. The BOTMP assesses the motor functioning of children from 4.5 to 14.5 years of age. Normative data based on the performance of a selected sample include standard scores for each age group. In general, the reliabilities for the various composite scores are satisfactory. The reliability coefficients for the Gross and Fine Motor parts range from 0.68 to 0.88. Test–retest coefficients for the separate subtests range from 0.58 to 0.89 for Grade 2 and from 0.29 to 0.89 for Grade 6.

To enhance the current study’s ecological validity, this subtest was used to create a prolonged graphomotor performance similar to which occurs in class.

**Handwriting measures**

The paragraph copy written by participants was the source for handwriting product and process measures:

*Global legibility.* This is an outcome measure that refers to the overall clarity of the handwriting product. It was scored in this study according to the scale of Ziviani and Watson-Will [29], ranging from 1 = the least legible to 7 = the most legible.
Children who met the inclusion criteria were evaluated in a quiet room in their homes. As presented in Table I, the study procedure included two sessions. In the first session (A), tripod pinch strength was evaluated (A1). Then the child was asked to complete the Bruininks-Oseretsky Visual-Motor Control subtest (A2) and to perform the handwriting copying task (A3), both of which were performed through use of the ComPET. These graphomotor tasks were followed by another evaluation of tripod pinch strength (A4).

After a 15-min rest break, the second session (B) began with an evaluation of tripod pinch strength (B1). The child again performed the same graphomotor tasks, but in the opposite order: first the handwriting copying task (B2) and then the Bruininks-Oseretsky Visual-Motor Control subtest (B3), both through use of the ComPET. Then tripod pinch strength was evaluated again (B4).

The average amount of time for children to complete the set of tasks (without including the break time) was 40 min (20 min per set).

All children were evaluated by an occupational therapist, who was blinded to group inclusion criteria.

**Statistical analysis**

Repeated measures analyses were used to explore (1) whether there were differences in tripod pinch strength along the course of the four measures (A1, A4, B1 and B4); (2) whether there were differences in the handwriting process and product measures between the two sessions (A3, B2), as determined by Ziviani’s and Watson-Will [29] global legibility evaluation and the ComPET.

In each group, paired t-tests were used to (1) confirm the existence of differences between tripod pinch strength in measures A1 versus A4; (2) examine whether there were differences in the handwriting process and product measures between the two sessions (A3, B2).

Independent t-tests were used to evaluate the significance of the difference between the groups in global legibility [29] of the writing product. In addition to hypotheses examination, a discriminant analysis was conducted to determine which variables (tripod pinch strength or handwriting process and products measures) were the best predictors of group membership (i.e. children with dysgraphia vs. TD peers). The level of significance for all performed analyses was set at 0.05.

**Results**

**Hypothesis 1: comparison of performance between groups**

**Tripod pinch strength.** A significant difference was found between the groups for tripod pinch strength ($F(1, 43) = 10.55, p = 0.002$; with the effect size of $ES-\eta^2 = 0.2$). As presented in Table II, this significant difference between groups was found for all four measures.

**Handwriting product and process measures**

A measure of handwriting product legibility [29]. The children with dysgraphia scored significantly lower on global legibility than did the TD peers on the first measure (mean of children with dysgraphia $= 4.61 \pm 0.89$; mean of TD peers $= 5.47 \pm 0.81$) ($t = -3.81, p \leq 0.0001$), as well as on the second measure (mean of children with dysgraphia $= 4.48 \pm 0.91$; mean of TD peers $= 5.91 \pm 0.69$) ($t = -6.47, p \leq 0.0001$).

**Handwriting process as measured by the ComPET.** A significant group effect on handwriting process measures was demonstrated ($F(9, 34) = 6.02, p < 0.0001, ES-\eta^2 = 0.615$). When examining each measure of the ComPET, a significant group effect

<table>
<thead>
<tr>
<th>Time 1 A1. Tripod pinch strength measure</th>
<th>Typical children (n=28)</th>
<th>Children with dysgraphia (n=23)</th>
<th>F(1, 43)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time 2 A4. Tripod pinch strength measure</td>
<td>Mean 3.25, SD 0.7</td>
<td>Mean 3.32, SD 1.04</td>
<td>4.18*</td>
</tr>
<tr>
<td>Time 2 15-min rest</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time 3 B1. Tripod pinch strength measure</td>
<td>Mean 3.64, SD 0.74</td>
<td>Mean 3.04, SD 0.97</td>
<td>5.76*</td>
</tr>
<tr>
<td>Time 3 B2. Performance of copying task from the HHE on ComPET</td>
<td>Mean 3.75, SD 0.68</td>
<td>Mean 3.05, SD 1.04</td>
<td>7.32**</td>
</tr>
<tr>
<td>Time 3 B3. Performance of Bruininks-Oseretsky Visual-Motor Control subtest</td>
<td>Mean 3.68, SD 0.64</td>
<td>Mean 2.59, SD 0.94</td>
<td>21.61***</td>
</tr>
</tbody>
</table>

*p < .05; **p < .001; ***p < .0001.
was found for mean pressure ($F(1, 42) = 5.93$, $p = 0.019$, ES-$\eta^2 = 0.124$).

Table III summarises the means and standard deviations of ComPET measures in each group, in the two sessions.

### Hypothesis 2: effects of protracted activities on graphomotor performance

**Tripod pinch strength.** According to the repeated measures test, a significant effect of session number on tripod pinch strength was found ($F(3, 129) = 8.29$, $p < 0.0001$; ES-$\eta^2 = 0.162$). According to the contrast test, a significant difference was found between the first measure (A1) and the second measure (A4) ($F(1, 43) = 8.73$, $p = 0.005$; ES-$\eta^2 = 0.17$), and between the third measure (B1) and the fourth measure (B4) ($F(1, 43) = 10.44$, $p = 0.002$; ES-$\eta^2 = 0.195$).

When examining the interaction between group and tripod pinch strength, a significant effect was revealed ($F(3, 129) = 3.7$, $p = 0.014$; ES-$\eta^2 = 0.08$). This effect was found to be significant between the third (B1) and the fourth (B4) measures ($F(1, 43) = 5.93$, $p = 0.02$; ES-$\eta^2 = 0.12$). While children with typical writing abilities had relatively similar pinch strength, children with dysgraphia showed deterioration in pinch strength, especially in the fourth measure (B4) (Figure 2).

Paired $t$-tests showed that among children with dysgraphia, there were significant differences indicating deterioration in tripod pinch strength between the first measure (A1) and the second measure (A4) ($t = 3.072$, $p = 0.006$), and between the third measure (B1) and the fourth measure (B4) ($t = 3.69$, $p = 0.001$). Among the typical children, no significant differences were found between the four measurements of pinch strength.

**A measure of handwriting product legibility [29].** When comparing global legibility within groups, among children with dysgraphia, no significant difference was found between both measures, while among the TD peers, significantly better global legibility was found in the second measure ($t = -3.67$, $p = 0.001$).

![Figure 2. Tripod pinch strength values in the four measures, in each groups.](image)

<table>
<thead>
<tr>
<th>Writing process measures</th>
<th>Typical children ($n = 28$)</th>
<th>Children with dysgraphia ($n = 23$)</th>
<th>$F$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>First session</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean pressure</td>
<td>778.74</td>
<td>684.57</td>
<td>5.033*</td>
</tr>
<tr>
<td>Mean speed</td>
<td>34.76</td>
<td>32.59</td>
<td>1.735</td>
</tr>
<tr>
<td>On-paper time per stroke</td>
<td>0.29</td>
<td>0.32</td>
<td>2.111</td>
</tr>
<tr>
<td>In-air time per stroke</td>
<td>0.55</td>
<td>0.46</td>
<td>2.304</td>
</tr>
<tr>
<td>On-paper length per stroke</td>
<td>7.17</td>
<td>7.71</td>
<td>0.212</td>
</tr>
<tr>
<td>Mean stroke width</td>
<td>2.15</td>
<td>2.1</td>
<td>0.408</td>
</tr>
<tr>
<td>Mean stroke height</td>
<td>3.55</td>
<td>4.01</td>
<td>1.549</td>
</tr>
<tr>
<td><strong>Second session</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean pressure</td>
<td>782.2</td>
<td>695.8</td>
<td>4.336*</td>
</tr>
<tr>
<td>Mean speed</td>
<td>34.68</td>
<td>35.33</td>
<td>0.001</td>
</tr>
<tr>
<td>On-paper time per stroke</td>
<td>0.28</td>
<td>0.31</td>
<td>3.266</td>
</tr>
<tr>
<td>In-air time per stroke</td>
<td>0.52</td>
<td>0.42</td>
<td>0.537</td>
</tr>
<tr>
<td>On-paper length per stroke</td>
<td>6.83</td>
<td>8.12</td>
<td>5.046*</td>
</tr>
<tr>
<td>Mean stroke width</td>
<td>2.04</td>
<td>2.26</td>
<td>2.477</td>
</tr>
<tr>
<td>Mean stroke height</td>
<td>3.41</td>
<td>4.13</td>
<td>6.226*</td>
</tr>
</tbody>
</table>

*Measure units: pressure, 0–1023; speed, mm/s; time, in seconds; spatial (length, width, height), in mm.
Handwriting process as measured by the ComPET

General effect of session on handwriting process measures. According to the repeated measures test, a significant effect of session number on handwriting process measures (A3 and B2) was found ($F(9, 34) = 3.45, p = 0.004, \text{ES-} \eta^2 = 0.472$). Specifically, a significant session effect was found for mean writing velocity ($F(1, 42) = 5.16, p = 0.028, \text{ES-} \eta^2 = 0.109$); total time per stroke ($F(1, 42) = 14.01, p = 0.001, \text{ES-} \eta^2 = 0.25$); on-paper time per stroke ($F(1, 42) = 14.47, p < 0.0001, \text{ES-} \eta^2 = 0.256$); and in-air time per stroke ($F(1, 42) = 9.55, p = 0.004, \text{ES-} \eta^2 = 0.185$).

Session × group interaction. No significant interaction effect of session × group on handwriting process measures was found. A significant session × group interaction effect was found for the following parameters: mean stroke width ($F(1, 42) = 11.85, p = .001, \text{ES-} \eta^2 = 0.22$); mean stroke height ($F(1, 42) = 6.98, p = 0.012, \text{ES-} \eta^2 = 0.143$); mean writing velocity ($F(1, 42) = 5.79, p = 0.021, \text{ES-} \eta^2 = 0.121$); on-paper length per stroke ($F(1, 42) = 9.64, p = 0.003, \text{ES-} \eta^2 = 0.187$).

Paired $t$-tests revealed that among the children with dysgraphia, significant differences between sessions in handwriting process measures (A3 and B2) were found for mean writing velocity (significantly slower in the second session); total time per stroke; on-paper time per stroke; in-air time per stroke (significantly higher in the second session). Among the typical children, the following handwriting process measures were significantly higher in the second session: mean stroke height and width; on-paper time per stroke; on-paper length per stroke (Table IV).

It should be noticed that when stroke pressure and task-completion time were used as covariates in the pre-post analysis of pinch pressure, no significant differences were found, meaning that these parameters had no significant effect on pinch strength.

The main effect on pinch strength, as mentioned earlier, was the group factor.

Discriminant analysis

One function predicted the categorisation of children with dysgraphia and TD peers (Wilks’ Lambda = 0.30; $p < 0.001$). This one function discriminated between the children with dysgraphia while they had lower scores ($-1.64$) and TD peers having higher scores ($1.35$).

The variable that made the greatest contribution to group membership was the handwriting product legibility (loading = 0.61), followed by the tripod pinch strength (3d) (loading = 0.45), mean stroke width (loading = −0.26) and the ground length per stroke (loading = −0.25).

On the basis of this function, 90.5% of the participants overall, 89.5% of the children with dysgraphia group and 91.3% of the TD peers were correctly classified. A Kappa value of 0.80 ($p < .001$) was calculated, demonstrating that the group classification did not occur by chance.

Discussion

This study aimed to examine the impact of graphomotor tasks of prolonged duration on tripod-pinch strength, and on handwriting process and product measures of children with dysgraphia and typical peers. This was achieved using handwriting assignments in a setting that imitates a daily school scenario for children in the third to fifth grades – a time in which writing skills are being acquired, but difficulties in handwriting performance are starting to be recognised.

Both hypotheses of this study were confirmed. Significant differences between children with dysgraphia and typically developed children were found in all tested measures. Moreover, effects of protracted

<table>
<thead>
<tr>
<th>Writing process measures</th>
<th>Typical children ($n = 28$)</th>
<th>Children with dysgraphia ($n = 23$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean pressure</td>
<td>−4.69</td>
<td>−11.05</td>
</tr>
<tr>
<td>Mean speed</td>
<td>0.28</td>
<td>−2.55</td>
</tr>
<tr>
<td>On-paper time per stroke</td>
<td>0.016</td>
<td>0.16</td>
</tr>
<tr>
<td>In-air time per stroke</td>
<td>0.028</td>
<td>0.43</td>
</tr>
<tr>
<td>On-paper length per stroke</td>
<td>0.36</td>
<td>−0.34</td>
</tr>
<tr>
<td>Mean stroke width</td>
<td>0.11</td>
<td>−0.14</td>
</tr>
<tr>
<td>Mean stroke height</td>
<td>0.16</td>
<td>−0.11</td>
</tr>
</tbody>
</table>

Table IV. Mean differences in writing process measures for both sessions of writing assignments between the groups according to the COMPET.

*Measure units: pressure, 0–1023; speed, cm/s; time, in seconds; spatial (length, width, height), in mm.
assignments on graphomotor performance were found to be greater among the children with dysgraphia, and deterioration in performance was mainly emphasised in tripod pinch strength and in the handwriting process, expressed in writing velocity, as well as in spatial measures, temporal measures and pressure.

To the best of our knowledge, this is one of the first studies to compare the tripod pinch strength of children with dysgraphia and their typical peers. This study indicated that children with dysgraphia showed deterioration in pinch strength, after performing graphomotor assignments, primarily in the final measurement.

In this study, no significant difference was found between both measures of global legibility and handwriting product and process among children with dysgraphia, while significantly better global legibility was found in the second measure of the TD peers. It might be suggested that following their first experience, TD children learned the task’s requirements and improved their performance [33].

This study results support previous findings that refer to handwriting product and process measures of children with dysgraphia. Engel-Yeger et al. [34] found that children with dysgraphia in second and third grade had significantly lower global legibility and significantly impaired handwriting process measures, compared to typical peers, as measured by the ComPET. In this report, children with dysgraphia had longer total performance time; longer on-paper time; in-air time; total path length as evaluated by ComPET.

This study supported these results and illuminated the impacts of prolonged graphomotor assignments and the impacts of fatigue: on performance velocity (children with dysgraphica wrote slower in the second session), spatial measures (stroke height and width increased in the second session) and pressure (which were found to be lower in children with dysgraphia in each of the sessions). In this regard, writing activity may be also analysed by the biomechanical model of the forearm suggested by Freund and Takala [35]. In this model, the researchers related to the ability to calculate the muscle forces according to external forces and a known motion and also mentioned the role of fatigue in this calculation. This model refers to the redistribution of the muscle forces for a fixed position and loading, as found in writing activity.

Taking it all together, decremented pinch force, which may result from fatigue, could be associated with a reduced motor control, as was expressed in this study by the association between lower muscle strength and poor handwriting.

It may be suggested that the decremented pinch strength may be related to the redundancy of forearm muscles or “load-sharing” and that children with dysgraphia are deploying inefficient control strategies that preferentially stress specific muscles [35]. This issue should be further examined in additional studies related to actual measurement of muscle activity while writing.

This study highlighted that fatigue is an important problem of prolonged exposure to writing-related tasks and activities. Missenard et al. [20] explained that when there is a need to preserve task success and reach a target fast and accurately (as in handwriting assignments) despite fatigue-induced changes within the neuromuscular system (which may be experienced in class by children with dysgraphia), subjects generally choose a compromise between speed and accuracy, meaning that movements are slower to guarantee task success in the presence of fatigue. Moreover, neuromuscular fatigue is accompanied by increased motor noise, which refers to a greater amount of undesirable movements [36].

Additional studies referred to the relationship between impaired kinesthetic function and the lack of motor control in handwriting, and noted its contribution to incorrect size/placement of letters and relationship of parts [37] which leads to decreased handwriting legibility. Indeed, in this study, the global legibility of the children with dysgraphia was lower than that of the TD peers. Dennis and Swinth [21] also found that school-aged children’s legibility was greater on a short task than on a long task.

Deterioration in handwriting performance was also highly manifested when evaluating handwriting process measures. Among the children with dysgraphia, greater on-paper length and in-air time were combined with lower velocity. These findings are in line with previous reports of this relationship [9]. Naider-Steinhart and Katz-Leurer [12], who evaluated typical children from third and fourth grade, found that a decrease in the strength of the thumb muscles was significantly associated with a reduced speed of writing. Feder and Majnemer [37] emphasised that children’s inability to acquire the automatic production of alphabet letters may adversely affect their speed. Since this automaticity is essential to the early stages of learning to write, early screening for handwriting deficiencies and early intervention when needed is of the utmost importance.

This study, as well as the study of Hooke et al. [5] highlight the importance of using pinch force measurement and the actual forces that might be applied to the writing instrument in a dynamic ‘real context’ of writing performance, especially in populations that are prone to difficulties in writing performance, as children with dysgraphia.

In summary, this study supports the assumption that prolonged exposures to fine motor demands in the classroom may negatively affect writing proficiency. Children with dysgraphia are more
vulnerable to prolonged graphomotor assignments. This is expressed by their higher and faster fatigue manifested in their lower muscle strength and impaired graphomotor performance. Impaired handwriting abilities may predict general learning difficulties later on [38]. In consideration of class time constraints, dysgraphia may interfere with the relationship between the child and the teacher [39], as well as those between the child and class peers, leading to a decline in the child’s self-esteem [40]. Since dysgraphia in children may be considered a lasting psychomotor deficiency and not a transient developmental delay [41], it should be early screened and treated to minimise its negative outcomes. Handwriting assessment should take into account general visual-motor abilities, handwriting process and product measures and tripod pinch. This information should be included in designing interventions for handwriting deficiencies [42]. Teachers may assist children with dysgraphia by permitting a longer time for accomplishing class assignments and by allowing for muscle relaxation while performing these assignments.

Declaration of interest: The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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