Research Article

Effect of pencil grasp on the speed and legibility of handwriting after a 10-minute copy task in Grade 4 children

Heidi Schwellnus,1 Heather Carnahan,2 Azadeh Kushki,3 Helene Polatajko,4 Cheryl Missiuna5 and Tom Chau6

1Graduate Department of Rehabilitation Science, University of Toronto, Toronto, Ontario, Canada, 2Department of Occupational Science and Occupational Therapy, University of Toronto, Toronto, Ontario, Canada, 3Bloorview Research Institute, Holland Bloorview Kids Rehabilitation Hospital, Toronto, Ontario, Canada, 4Graduate Department of Rehabilitation Science, University of Toronto, Toronto, Ontario, Canada, 5School of Rehabilitation Science, Director, CanChild, Centre for Childhood Disability Research, McMaster University, Toronto, Ontario, Canada and 6Canadian Research Chair in Paediatric Rehabilitation Engineering, Bloorview Research Institute, Toronto, Ontario, Canada

Aim: To investigate the impact of common pencil grasp patterns on the speed and legibility of handwriting after a 10-minute copy task, intended to induce muscle fatigue, in typically developing children and in those non-proficient in handwriting.

Methods: A total of 120 Grade 4 students completed a standardised handwriting assessment before and after a 10-minute copy task. The students indicated the perceived difficulty of the handwriting task at baseline and after 10 minutes. The students also completed a self-report questionnaire regarding their handwriting proficiency upon completion.

Results: The majority of the students rated higher effort after the 10-minute copy task than at baseline (rank sum: P = 0.00001). The effort ratings were similar for the different grasp patterns (multiple linear regression: F = 0.37, P = 0.895). For both typically developing children and those with handwriting issues, the legibility of the writing samples decreased after the 10-minute copy task but the speed of writing increased.

Conclusions and Significance of the Study: The quality of the handwriting decreased after the 10-minute copy task; however, there was no difference in the quality or speed scores among the different pencil grasps before and after the copy task. The dynamic tripod pencil grasp did not offer any advantage over the lateral tripod or the dynamic or lateral quadrupod pencil grasps in terms of quality of handwriting after a 10-minute copy task. These four pencil grasp patterns performed equivalently. Our findings question the practice of having students adopt the dynamic tripod pencil grasp.

KEY WORDS dysgraphic, fatigue, grips, handwriting, paediatrics.

Introduction

Handwriting is an important functional skill for school-aged children. In primary school, children are required to write with pencil and paper for a large part of their schoolwork as well as for tests and notes, although some of the burden of writing has been alleviated by computers (McHale & Cermak, 1992). Longcamp et al. (2008) recently argued that unlike keyboarding, the memory of motor actions involved in letter writing has a significant impact on the long-lasting recognition of shapes and letters. Letters learned by hand are recognised more accurately and for longer periods and can be distinguished from mirror images better than letters learned by keyboarding (Longcamp et al.). Thus, the importance of learning handwriting should not be underestimated.

The majority of children learn to write in the first few grades of school. In North America, children learn manuscript in the first three years and then learn cursive writing beyond the third grade. It is estimated that
between 3% and 27% these children have difficulty with this essential task of writing (Graham, Berninger, Weintraub & Schafer, 1998b; Smits-Engelsman, Niemeijer & van Galen, 2001). Poor handwriting performance, namely reduced speed and legibility, has been linked to decreased self-esteem and lower academic achievement (Graham et al.). To assist these children, they are frequently referred to school-care occupational therapists (Overvelde & Hulstijn, 2011).

Handwriting and pencil grasp
Poor pencil grasp has commonly been the target of intervention by both teachers and occupational therapists, who attempt to alter the child’s pencil grasp from anything different from the traditional dynamic tripod grasp (Feder & Majnemer, 2007; Graham et al., 2008). Schneck (1991) found that poor writers had less mature pencil grasps, although later research failed to replicate these results (Tseng & Cermak, 1993). A dynamic or mature pencil grasp, specifically the dynamic tripod grasp, has been suggested as the best grasp for writing because it allows for efficient distal movements of the pen or pencil (Elliott & Connolly, 1984) and purportedly minimises muscle tension that can lead to fatigue (Tseng & Cermak; Ziviani, 1983). In contrast, a static or immature pencil grasp is one in which the pencil is held by the fingers, but the movement of the pencil is controlled by the extrinsic muscles of the hand and arm, while the fingers remain static (Elliott & Connolly).

There are at least four pencil grasp patterns that are mature and therefore functional for handwriting: the traditional dynamic tripod grasp and three other grasps, including the lateral tripod grasp; the dynamic quadrupod grasp and the lateral quadrupod grasp (Tseng & Cermak, 1993; Ziviani, 1983). These grasps are described in detail below. Although the name of the lateral grasps does not imply dynamic movement, in these mature grasps, the fingers are dynamic and supply movement while the thumb is static (Elliott & Connolly, 1984).

1. Dynamic tripod (DT): This grasp is most commonly recommended (Schneck & Henderson, 1990). Fingers involved include the thumb opposed to the index and middle fingers, with all three fingers positioned in a tripod (Benbow et al., 1992). The ring and little finger stabilise against the writing surface.

2. Lateral (thumb) tripod (LT): Also a common grasp described in the literature (Schneck & Henderson, 1990). The thumb is adducted to the lateral border of the index finger or crosses over top of the pencil. The index and middle fingers are predominantly the source of pencil movements without the thumb because its position restricts participation.

3. Dynamic quadrupod (DQ): Identified by Benbow (1987), this grasp is similar to the dynamic tripod; however, it involves the addition of the ring finger on the barrel of the pencil. Similar distal manipulation of the pencil occurs, as with the tripod; however, surface stabilisation may be less due to the inclusion of the ring finger in the pencil grasp.

4. Lateral (thumb) quadrupod (LQ): Dennis and Swinth (2001) identified this grasp involving four fingers. The thumb is in an adducted position and the index, middle and ring fingers are in contact with the barrel of the pencil, and therefore initiate the pencil movement.

Performance was similar for these grasps for short duration copy tasks, where the speed and legibility of the written output was not significantly different (Schwellnus et al., 2011). The three other grasps may require excessive effort to maintain over longer periods of writing. With the dynamic tripod grasp, the distal control of the movement allows the muscles to have consistent pressure on the pencil and therefore minimises muscle tension, which can lead to muscle fatigue (Soechting & Flanders, 2008). Although writing is a low force activity, fatigue has been reported in the muscle groups involved in grasping a pen during writing for 10 minutes (Parush, Pindak, hahn-Markowitz & Masor-Darsenty, 1998). This is due to the isometric muscle effort expended to control the many joints involved in maintaining the grasp of the pencil during writing, and this effort can lead to fatigue over time (Udo, Otani, Udo & Yoshinaga, 2000).

Pencil grasps and muscle fatigue
The four mature grasp patterns use similar groups of muscles in the hands and forearm and involve intrinsic muscle function necessary for fine manipulation of the writing utensil to form letters (Long, Conrad, Hall & Furler, 1970). The amount of effort required to write becomes more significant as children progress through school and the length of assignments increases (Cornhill & Case-Smith, 1996). During prolonged writing, the speed and legibility of both adults’ and childrens’ writing are impacted (Dennis & Swinth, 2001; Tseng & Cermak, 1993). The impact on the quality and quantity are proposed to be the result of the increased muscle effort expended over longer writing tasks, which results in fatigue (Ziviani, 1983).

Stevens (2008) conducted a study comparing the dynamic tripod, lateral tripod grasp and a group of all other grasp patterns in adults. The participants copied until they could not write anymore. The group with the lateral tripod grasp wrote the same number of words but stopped writing (were fatigued) earlier than the other two groups. The author suggested that while the lateral tripod grasp was functional, this grasp might be more susceptible to fatigue than the other grasp patterns. In a similar vein, Dennis and Swinth (2001) evaluated the impact of task length (short versus long writing task) and pencil grasp (dynamic tripod versus atypical grasps) on the legibility of children’s writing.
The ‘atypical grasps’ category included all the other functional writing grasps such as the dynamic quadrupod, the lateral tripod and the lateral quadrupod and any other writing grasp observed. Although the legibility of the short tasks was better than that of the long tasks, they did not find that grasp pattern impacted speed or legibility, nor was grasp type influenced by task length (Dennis & Swinth). Due to the modest study sample, the group with ‘atypical’ grasp could not be further subdivided for finer grained analyses. In addition, the authors did not use a standardised handwriting assessment and in fact, varied the task among participants, precluding comparisons to other studies and confounding the between-group analyses. Parush, Pindak, Hanh-Markowitz and Mazor-Karsenty (1998), evaluated children’s handwriting quality and writing speed before and after a 10-minute copy task. This task duration was selected through teacher consultation as being sufficient to induce physical fatigue. Parush and colleagues monitored the stability of the pencil grasp pattern (whether the child maintained or changed grasp pattern) but did not identify the type of pencil grasp utilised, nor was fatigue specifically measured. The quality of the writing of both the proficient and the non-proficient groups decreased after the 10-minute copy task; however, writing speeds of both groups increased. Overall, the study suggested that children take breaks when writing for prolonged time, but made no recommendations regarding pencil grasp.

The systematic investigation of the impact of fatigue and pencil grasp on the quality of handwriting is necessary because children write for increasingly longer times as they progress through school (Reid, Chiu, Sinclair, Wehrmann & Naseer, 2006). Muscle fatigue, often associated with heavy exercise, is defined as an ‘acute impairment of performance that includes both an increase in the perceived effort necessary to exert a desired force and an eventual inability to produce this force’ (Enoka & Stewart in Barry & Enoka, 2007, pp. 465). Without rest, debilitating fatigue can result in the deterioration of both the quality as well as the speed the task performed. In studying the impact of fatigue on handwriting, Provins and Magiaro (1989) occluded blood flow to the writing arm, which resulted in deterioration of both the speed and quality of handwriting.

The measurement of muscle fatigue in low intensity activity is challenging, particularly in young children due to its abstract and subjective nature. Review of the current literature revealed little information on the measurement of fatigue during a specific low intensity activity. Most studies quantified overall body fatigue in children with a degenerative disease or cancer, neither of which is applicable to the current investigation. The literature on perceived effort or exertion has focussed, for the most part, on healthy children. Perceived effort refers to the subjective difficulty of a task, which is of interest in the current handwriting study and consistent with the definition of fatigue above. There are a number of perceived exertion scales valid for young children (Groslambert, Hintzy, Hoffman, Dugué & Rouillon, 2001). From the literature, children from 8 to 14 are able to assess their perceived effort (Groslambert et al.). A scale with the combination of pictures and words works best with children (Yelling, Lamb & Swaine, 2002), and children do best when they have explicit instructions as to how to use the scale, although the depicted activity does not necessarily have to be the same as the activity performed (Eston, 2009).

Additional research is needed to investigate two aspects of increased writing. The first is whether or not pencil grasp, specifically the dynamic tripod, the dynamic quadrupod, the lateral tripod and the lateral quadrupod, is impacted by a prolonged writing task. These four grasps have been found to produce equally functional writing over a short duration of time (Schwellnus et al., 2011). The second aspect needing further investigation is whether or not longer writing tasks impact the functionality of the chosen pencil grasp, in terms of speed and legibility of writing. The objective of the current study was to investigate the impact of pencil grasp on the speed and legibility of the writing before and after a long copy task.

**Methods**

**Participants**

A volunteer sample of 120 Grade 4 students was recruited from a local municipal school board. The Toronto District School Board and University of Toronto approved the study. Written consent was obtained from parents of study participants and verbal assent was obtained from the children at the time of the study. The children were enrolled in four schools in a fairly close geographical area in a metropolitan city. The school neighbourhoods were considered to be middle to upper middle class based on socioeconomic status of the school catchment area. Eight teachers consented to the study in their classes.

**Protocol and Instruments**

The participants were tested in a small quiet room within the school during regular school hours. Most assessments occurred during the months of May and June; however, a new cohort of 16 Grade 4 children was tested in October of the subsequent school year. The participants were seated on a height adjustable chair at a regular school table. They were initially positioned with their feet supported on the floor or the footplate of the chair. The children were videotaped with a Sony Digital Video Recorder from the non-dominant side for a sagittal view of the writing session. The children wrote with an instrumented self-inking pen directly on a tablet, no paper was used. The pen is comparable to a
EFFECT OF PENCIL GRASP ON HANDWRITING WHEN FATIGUED

primary school pencil in diameter (11 mm or 0.43 inches) and had a high friction tip, which simulated writing on paper. This equipment was used as part of a larger study, which investigated writing grip forces.

The children completed a standardised writing assessment, the Children’s Handwriting Evaluation Scale or CHES, twice, once before a copy task (time 1) and again after the copy task (time 2) (Phelps, Stemple & Speck, 1985). The manuscript version (CHES-M) is available for students in Grades 1 and 2 while the cursive version (CHES) is suited to children beyond Grade 2. Both assessments evaluate handwriting speed and legibility on the basis of two minutes of writing with pencil and paper, namely, copying two sentences for the CHES-M and five for the CHES both completed at regular copy speed. Both versions have excellent psychometric properties (intra-reliability of 0.82 and inter-reliability of 0.95) (Phelps et al., 1985). Children are identified as requiring remediation if they score poorly (see below) on at least one of speed or legibility.

In the current study, all students wrote in manuscript form. Because there is no standardised handwriting assessment for manuscript writing for Grade 4 students, CHES-M legibility criteria were used for scoring the legibility of the writing. Grading criteria from a standardised handwriting assessment have been applied to non-standardized writing material (Dennis & Swinth, 2001). The 10 criteria are scored for each writing sample and a raw score calculated out of 100 in increments of ten. A quality score of 80–100 indicates good legibility, a score of 50–70 indicates satisfactory legibility and a score of 40 or below indicates poor legibility signalling the need for remediation. Because the age of the current sample was higher than that of the CHES-M norms for legibility, the 15th percentile for our sample was used as a cut-off for non-proficiency, which resulted in a threshold score of 30 instead of the reported 40 (Graham, Struck, Santoro & Berninger, 2006).

Speed of writing is dependent upon the method of writing, and norms for higher grades are based on cursive writing. An inter-rater reliability of 0.82 was achieved for the classification of pencil grasp pattern based on 35 of the participant videos scored by the same two raters. Intra-rater for the primary author for grasp classification for 10 students from video was 0.80.

Matlab version 7.9.0 and Statistical Analysis Software version 9.2 were used for data analysis. Multiple linear regression (Armitage, Berry & Matthews, 2008) was used to evaluate the relationships between perceived effort and grasp pattern while controlling for writing proficiency as measured by CHES legibility scores at time 1 (T1). The following variables were included in the model: gender, handedness, school and time of assessment (June or October). Teacher was initially included but was not significant and subsequently removed from the model. To evaluate the significance of changes in PCERT scores, we used the Wilcoxon rank-sum test, as the data were not normally distributed. To test the change in the CHES legibility and speed scores between T1 and T2, a paired t-test was used. A Chi-Squared test was used to test the relationship between the PCERT scores of girls and boys. Unless otherwise specified, a significance level of 5% was used in statistical testing. Cohen’s d was used for calculating effect sizes.

Results

Sample demographics

The volunteer sample of 120 participants was almost equally divided between girls and boys, with 49% boys
and 51% girls. The participants’ mean age was 9 years 11 months (± 4.32 months). Seven per cent of the sample was of left-handed writers, which is within expectations for dominance. The participants had a mean age of 9 years 11 months. The students used four common grasps: the dynamic and lateral tripod as well as the dynamic and lateral quadrupod grasps. In addition, three other grasp categories were observed: a combination of the four-fingered grasp and the interdigital grasp (Tseng, 1998), a grasp which alternated between the dynamic tripod and the lateral tripod, and a grasp which alternated between the dynamic quadrupod and the lateral quadrupod. The distribution of the grasp patterns is depicted in Figure 1.

Legibility
Recall that legibility was scored according to the CHES-M criteria. Within-participant comparisons were based on raw scores only. The legibility scores for the CHES before and after the 10-minute copy task are shown in Figure 2. Legibility generally decreased after the fatigue task. Nineteen per cent of the sample had poor legibility (score of 30 or below) before the 10-minute copy task; however, after the copy task, 34% of the participants’ writing was of poor legibility. The CHES scores at T1 and T2 were statistically different (t-test $P < 0.0001$, CI = 8.45–14.22). The children wrote slightly more at T2, 56 vs. 54 LPM (t-test $P = 0.04$, CI = 0.14–4.69).

Perceived effort
The PCERT scores at T1, before any writing, and after the 10-minute copy task, i.e., at T3, were significantly different. Before the fatigue task the median rating was three; after the fatigue task the median rating was four (rank sum: $P < 0.00001$).

Grasp pattern
The multiple linear regression analysis revealed no significant differences in PCERT scores when compared by grasp pattern ($F(6, 105) = 0.49$, $P = 0.813$), while controlling for proficiency within the model. Twenty participants increased their scores in legibility; however, only one of those participants decreased their PCERT scores, or indicated that they were less fatigued after the 10-minute copy task. The covariates were included in the model, with significant relationships found for calendar date of assessment, $F(1, 105) = 9.55$, $P = 0.003$. The students from October (T2) had higher scores than those in May/June (T1). Gender ($F(1, 105)$, $P = 0.062$), school ($F(3, 105)$, $P = 0.194$), and handedness ($F(1, 105) = 5.10$, $P = 0.026$), were not significant when the Bonferoni correction was applied due to the number of comparisons, and the level of significance lowered to $P = 0.008$). Confidence intervals and effect sizes (calculated with Cohen’s d) for the results are presented in Table 1.

Conclusion
Impact of perceived effort on different pencil grasp patterns
We investigated the influence of perceived effort on the common grasp patterns. We found that grasp did not significantly affect perceived effort. In this study we used a 10-minute copy task to induce fatigue. The 10-minute copy task did appear to serve its purpose; the PCERT scores for perceived effort increased after the 10-minute copy task ($P = 0.0001$). The fact that there was no difference in rating of perceived effort between the children using the different pencil grasps may be due to the fact that the muscles involved in the different types of grasp are very similar, and therefore the grasps may have been equally affected by the long copy task.
Impact of perceived effort on legibility and speed of writing

The legibility of the writing samples decreased after the 10-minute writing task \( (P < 0.0001) \) across the entire sample, with no significant differences between the four grasp patterns. Previous explanations for decreased legibility with prolonged writing have included the natural tendency for individuals to write faster as time goes on (Udo et al., 2000) and diminishing interest in the writing task (Parush et al., 1998). Indeed, in the present study, we observed a speed increase accompanied by a decrease in legibility, which could be a manifestation of the speed-accuracy trade-off in handwriting (Weintraub & Graham, 1998). Legibility may have also decreased, in part, as a consequence of the overall tiredness that children reported.

All students wrote in manuscript, although traditionally by 9–10 years of age, cursive would be the expected style of writing in North America (Graham, Berninger...
investigate the impact of a longer copy task. The 10-minute task increased effort ratings, some children having lower scores on perceived effort than those in Grade 4, with the sample having lower scores on perceived effort than those in Grade 4. The students in May/June had been writing for seven months at the Grade 4 level and may have simply been more accustomed to writing for 10-minutes than their counterparts just starting Grade 4. The perceived effort results did not vary by school or by teacher. This is perhaps not surprising, given that all teachers are required to follow a standard curriculum for written communication.

Some limitations of our study include that our volunteer sample was derived from schools situated in middle and upper middle class neighbourhoods and thus may not be fully representative of Grade 4 children and therefore may not be applicable to all school children. The children wrote on a tablet with a self-inking pen, which is different from paper; however, writing on a tablet surface is a relatively common task with the current use of tablets and portable gaming systems. The CHES-M scoring had to be adapted to the increased age of the sample due to the continued use of manuscript, which posed a challenge; however, a standardised test of manuscript does not exist for this age group.

Additional research on this topic should include using a similar methodology with a larger sample of children including equal groups of proficient and non-proficient children. Various grades could also be investigated to determine whether there is more or less effect of fatigue as the amount of writing increases throughout the school curricula.

Overall, it appears that the different pencil grasp patterns were not affected differently by the 10-minute writing. The tripod grasp had been recommended as the best pencil grasp based on the well-coordinated movements from the interphalangeal joints and those of the hand and forearm (Benbow et al., 1992). Furthermore, literature has suggested that other grasp patterns commonly observed, including the dynamic quadrupod, lateral tripod and lateral quadrupod, may be more effortful. Our results do not support this conjecture. Neither speed nor legibility of writing was affected by these grasp patterns (Schwellnus et al., 2011).

In general, the dynamic tripod grasp may be recommended for children when commencing writing, but should a child have difficulties with his or her writing, the occupational therapists should first confirm the grasp being utilised. If the grasp pattern is either the dynamic tripod or dynamic quadrupod, the therapist should look beyond the pencil grasp in pinpointing the writing issue. Instead of targeting pencil grasp, remediation may focus on improving writing quality or speed or increasing practice time.

References


