Writing Forces Associated With Four Pencil Grasp Patterns in Grade 4 Children

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MeSH TERMS
- hand strength
- handwriting
- kinetics
- task performance and analysis

OBJECTIVE. We investigated differences in handwriting kinetics, speed, and legibility among four pencil grasps after a 10-min copy task.

METHOD. Seventy-four Grade 4 students completed a handwriting assessment before and after a copy task. Grip and axial forces were measured with an instrumented stylus and force-sensitive tablet. We used multiple linear regression to analyze the relationship between grasp pattern and grip and axial forces.

RESULTS. We found no kinetic differences among grasps, whether considered individually or grouped by the number of fingers on the barrel. However, when grasps were grouped according to the thumb position, the adducted grasps exhibited higher mean grip and axial forces.

CONCLUSION. Grip forces were generally similar across the different grasps. Kinetic differences resulting from thumb position seemed to have no bearing on speed and legibility. Interventions for handwriting difficulties should focus more on speed and letter formation than on grasp pattern.

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Handwriting is a skill that school-age children are required to master (Smits-Engelsman, Niemeijer, & van Galen, 2001). Even with the increased use of computers and tablets, handwriting remains an important skill, because the motor action of creating letters on paper has been found to increase the memory of letters beyond that attainable with keyboarding alone (Longcamp et al., 2008). James (2010) found that the creation of letterforms augmented the visual processing of letters in preschool children. Thus, the importance of learning to manually form letters cannot be underestimated.

The production of functional handwriting depends on the complex interplay of a number of abilities including skillful fine motor coordination and precise force regulation as well as cognitive, perceptual, and language skills (Van Galen, 1991). Understandably, given the need for this complex integration of skills, learning to write can be challenging for children.

Dysgraphia

When a child has handwriting difficulties without a diagnosis of a neurological or intellectual disability, the handwriting difficulties are often termed *dysgraphia* (Feder & Majnemer, 2007). Dysgraphia is characterized by difficulty in the production of legible writing, in maintaining the quantity and speed of writing demanded in class, or both. The number of typically developing children who struggle with handwriting varies, with reported prevalence worldwide ranging from 6% to 34% (Graham, Weintraub, & Berninger, 1998; Overvelde & Hulstijn, 2011; Smits-Engelsman et al., 2001).

Pencil Grasp Debate

Pencil grasps are commonly classified according to the position of the thumb, the number of fingers on the barrel of the pencil, and finger joint positions. In dynamic grasps, the thumb is positioned in opposition to the fingers; the thumb and fingers are placed on opposite sides of the pencil. In lateral grasps, the thumb crosses over the pencil, stabilizing it against the other fingers. However, the pad of the thumb tends to contact the lateral border of the index finger instead of the shaft of the pencil. Three fingers contact the barrel in a tripod grasp and four in a quadrupod grasp.

Although a child's pencil grasp pattern is commonly implicated in handwriting problems, this implication is not evidence based (Graham et al., 2008; Rigby & Schwellnus, 1999; Rosenblum, Dvorkin, & Weiss, 2006). Historically, the dynamic tripod (DT) pencil grip has been promoted as the optimal grasp pattern because it allows for the fine dexterous movements of the fingers to create letters (Elliott & Connolly, 1984). Therapists and teachers commonly recommend that children, especially those with handwriting difficulties, use the DT pencil grasp (Schneck & Henderson, 1990). Three other pencil grasp patterns—namely, the dynamic quadrupod (DQ), the lateral tripod (LT), and the lateral quadrupod (LQ) pencil grasps—are suggested to be mature grasps that are functional in terms of speed or legibility for writing (Dennis & Swinth, 2001; Koziatek & Powell, 2003). The prevalence of each of these grasp patterns in children is comparable to that of the DT grasp (Koziatek & Powell, 2003; Schwellnus et al., 2012). In mature pencil grasps, the intrinsic muscles of the hand are responsible for the movement of the pencil within the hand (Elliott & Connolly, 1984). In contrast, with immature pencil grasp patterns, the pencil is held with the fingers, but the movement is controlled by the extrinsic muscles (Elliott & Connolly, 1984).

A desirable feature of the DT pencil grasp is the facilitation of fluid and fine movements of the three fingers as they flex and extend to form vertical and curved letter strokes (Elliott & Connolly, 1984; Tseng, 1993). In addition, the ring and the fifth fingers provide stabilization against the palm and support the metacarpal phalangeal arch of the hand (Benbow, 2002; Ziviani & Wallen, 2006). The increased surface area of grasps other than the DT could decrease the dynamic movement of the pencil (Dennis & Swinth, 2001). With the lateral grasps, the thumb is adducted and the web space is closed more tightly around the barrel of the pencil, which restricts the pencil's movement, eliminates thumb opposition, and further compromises balance (Dennis & Swinth, 2001). Likewise, with the DQ grasp, the ring finger is in contact with the pencil barrel, thereby eliminating the radial–ulnar dissociation of the fingers. In turn, stabilization normally provided by the ring and fifth fingers against the palm of the hand is lost (Ziviani & Wallen, 2006). The vertical movements of the pen are therefore provided solely by the movement of the index, middle, and ring fingers, and the thumb is minimally involved in the movement of the pencil. The aforementioned movement restrictions may reduce the variability of grip force. Indeed, previous research has found that when grip force has a low amount of variability, handwriting quality is decreased (Falk, Tam, Schwellnus, & Chau, 2010).

For a pencil grasp to be functional for writing, it must offer the user the ability to efficiently create a legible written product for the required duration. Children must be able to write long enough to keep up with class work and to complete assignments and examinations as they progress through school. Stevens (2008) found that people who used the LT grasp produced the same quantity of work but stopped writing earlier than those using other grasps and therefore wrote faster. The dynamics of the LT grasp were suggested to cause earlier fatigue (Stevens, 2008), which may be the result of inefficient movements that are controlled proximally (Summers, 2001). Clearly, much debate still exists in the literature around the relative functional merits of the various pencil grasps. A closer look at the kinetic characteristics of different grasps may help to explain functional similarities and differences among grasps.

Grip and Axial Forces

Grip force is understood to be the forces exerted by the thumb and fingers on the barrel of the writing implement. The dynamic grasps with the opposed positioning are deemed to be balanced grasps because the forces exerted by the three (or four) digits intersect at a common point and therefore require minimal force to maintain (Soechting & Flanders, 2008). Grasps have also been categorized by the amount of hyperextension of the distal finger joints of the index finger (Selin, 2003; Ziviani, 1983) as a proxy for grip force. Recent research has indicated that grip force variability is a strong indicator of handwriting legibility (Falk, Tam, Schwellnus, & Chau, 2011) and that students with writing difficulties exhibit more static grip force patterns (Falk et al., 2010). Paired with the growing evidence that the different pencil grasps are functionally equivalent, these findings beg the question of whether the kinetic characteristics of different grasps are in fact similar.

The amount of surface contact with the pencil barrel varies with the different finger and thumb positions. In the quadrupod gasps, an additional finger is in contact with the barrel; in the lateral grasps, the adduction of the thumb reorients the pencil within the grasp and increases the barrel-to-finger contact area (Figure 1). The impact of this greater surface contact area on grasp function is unknown. Grasps other than the DT have been hypothesized to decrease the amount of force exerted by each digit by distributing the requisite force over a larger surface area. Alternatively, the broadened surface contact may increase the total grip force, rendering the grip more static, and in turn diminish the engagement of the intrinsic hand muscles (Dennis & Swinth, 2001).

Although the former hypothesis suggests that the grasp with more contact points would be more stable and may reduce fatigue, the increased stability has not been proven to be advantageous for writing (Wu & Luo, 2006). The broader surface area hypothesis suggests that grasp patterns with increased contact and pressure could be less functional than the DT grasp; the elevated pressure over time could increase the effort required to maintain the grasp, inducing premature fatigue, which could, in turn, decrease motor control and the legibility of writing (Dennis & Swinth, 2001; Engel-Yeger & Rosenblum, 2010). In fact, the LT grasp has been linked to earlier fatigue (Stevens, 2008). Evidently, grip forces may potentially modulate pencil grasp endurance, as well as the speed and legibility of the writing.

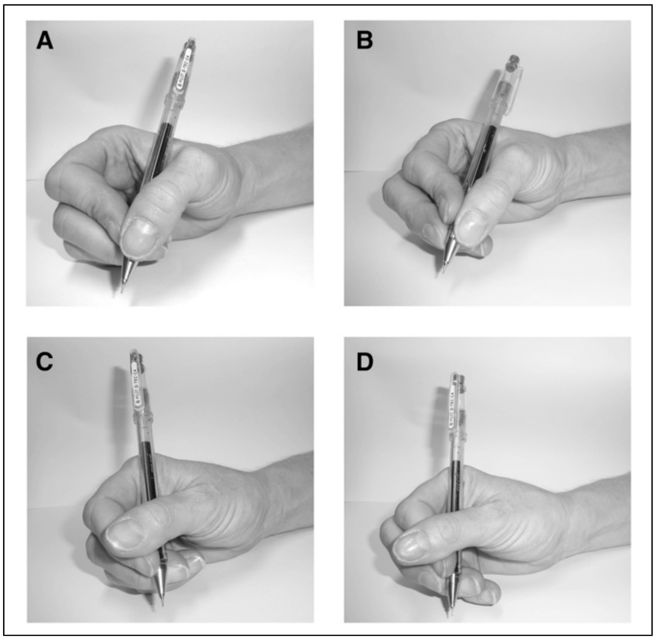

Figure 1. Four grasp patterns: (A) Dynamic tripod, (B) dynamic quadrupod, (C) lateral tripod, and (D) lateral quadrupod.

Axial force may also vary with pencil grasp pattern. *Axial force,* also termed *point pressure,* is the force applied downward from the writing utensil onto the writing surface (Harris & Rarick, 1957). The impact of greater barrel surface contact area on axial force is unknown; it may remain the same, increase, or decrease, depending on the number of digits involved and their orientation with respect to the barrel of the writing utensil. Last, the variability of axial force has been associated with decreased legibility of writing (Baur et al., 2006; Harris & Rarick, 1959), but again, the relationship between pencil grasp pattern and kinetic variability is unknown.

In light of the preceding, in this study we aimed to answer the following primary question: What are the kinetic differences, if any, among the four pencil grasp patterns, before and after an extended writing task? Second, we explored whether kinetic differences were related to functional differences in terms of speed and legibility.

Method

Participants

One hundred twenty Grade 4 students were recruited as a volunteer sample from four schools within a metropolitan school board. Previous grip force studies have suggested that a sample size between 9 and 16 per group is required to detect a large effect on various force parameters with 80% power (Chau, Ji, Tam, & Schwellnus, 2006; Falk et al., 2010). The Statistics Canada (http://statcan.gc.ca) data on the schools' postal codes indicated that the average household income for the school catchment areas was in the middle- and upper-middle-class range. Both the school board's and the university's research ethics boards approved the study. Written consent from each parent was obtained, and each child assented to participate at the time of data collection.

Handwriting is relatively well developed by Grade 4, and the quality of writing has stabilized (Overvelde & Hulstijn, 2011). The students had been introduced to cursive writing and were old enough to write for a minimum of 10 min (Dennis & Swinth, 2001; Parush, Pindak, Hahn-Markowitz, & Mazor-Karsenty, 1998). Data collection was conducted in the spring for most of the students; however, to achieve the desired sample size of 120 students, an additional 16 students were recruited in the subsequent school year. These new recruits were derived from a new cohort of Grade 4 students and were assessed in the fall (thus, they were younger and less experienced writers than the spring cohort at the time of testing).

Instruments

To evaluate the grip and the axial forces, the students wrote with an instrumented pen on an electronically inking and digitizing tablet (Wacom Cintiq 12WX, Wacom, Vancouver, WA). The dimensions (width × height × thickness) of the tablet were 10.3 × 6.4 × 0.67 in. (261.6 mm × 162.6 mm × 11 mm). In the landscape orientation, the writing surface was similar in width to a regular letter-sized sheet of paper. The tablet was positioned in front of the children on a tabletop. The pen's construction is described in detail in Chau et al. (2006). The pen barrel was 0.43 in. (11 mm) in diameter, comparable to that of a primary school pencil. The high-friction tip of the pen simulated the pencil-on-paper writing experience. TekScan paper-thin sensors (Model 9811, Tekscan, Boston) were adhered to the circumference of the barrel to capture the grip force. The sensor strips were replaced 6 times throughout data collection sessions as a result of wear and tear. Recordings of the axial and grip forces were synchronized and stored on a laptop computer. The sampling periods for axial and grip forces were 7 ms and 4 ms, respectively. The axial data were linearly interpolated to match the sampling period of the grip data before analysis.

Handwriting Assessment

We used the Children's Handwriting Evaluation Scale (CHES; Phelps & Stempel, 1987). The CHES has both a manuscript version (CHES–M for Grades 1 and 2) and a cursive version (CHES for Grades 3 and beyond). We chose this assessment because it requires only 2 min to complete; in comparison, the Evaluation Tool of Children's Handwriting (Amundson, 1995) requires 15–20 min to complete. The selection of a brief assessment was necessary to minimize time out of the classroom. Students copy a standard text (two sentences in the CHES–M and five in the CHES). Both versions have scoring criteria to evaluate handwriting speed and legibility. The psychometric properties of the CHES–M and the CHES are intrarater reliability of .82 and interrater reliability of .95 (Phelps & Stempel, 1987). The CHES can be administered in 2 min. Either the quality or the speed score or both can be used to identify students with handwriting difficulties or dysgraphia.

Children are expected to use cursive writing by Grade 4 in North America (Dennis & Swinth, 2001; Graham et al., 1998); however, all the children in the study elected to use manuscript writing. All children had been taught cursive in school, but their teachers did not require its use in class, so a hybrid assessment was required. The children were old enough to copy the longer passage of the CHES, but because of their use of manuscript, we applied the CHES–M quality criteria. The quality score quantifies the legibility of the letters in the sample. The CHES–M has a total score of 100, with 10-point increments. A score of 80–100 indicates good legibility; 50–70, satisfactory; and ≤40, poor. Given that the sample age exceeded that of the normative data, the quality scores were plotted and the 15th percentile was selected as the cutoff (Graham, Struck, Santoro, & Berninger, 2006); therefore, children who scored ≤30 were identified as having writing difficulties. The CHES has twice as many words as the CHES–M and therefore has more chance of errors, so the lower score cutoff is justified. Writing speed was estimated in letters per minute (LPM). Neither the CHES–M nor CHES rate norms could be used because the age and writing format criteria were not met. The children were thus identified as dysgraphic solely on the basis of their quality scores.

Protocol

The participants were assessed in a quiet room in their own school during school hours. The children sat on a Stokke height-adjustable chair (Stokke LLC, Stamford, CT) facing a regular school table. A digital camcorder recorded a shoulder-to-knee sagittal view of the child's pencil grasp and the position of the trunk. The chair was initially positioned to support the children's feet to allow for the recommended 90° sitting posture (Parush, Levanon-Erez, & Weintraub, 1998); however, posture was recorded but not controlled during the study, allowing the children to assume their own comfortable writing positions. The primary author (Tom Chau), an experienced occupational therapist, conducted all the assessments. All children completed the CHES twice, once before a 10-min copy task (CHES 1) and once after the copy task (CHES 2). A 10-min-long copy task was previously found to be sufficient to fatigue Grade 3 students (Parush, Pindak, et al., 1998), and this duration of writing did significantly alter scores for perceived effort in Grade 4 students (Schwellnus et al., 2012).

To familiarize the children with writing on a tablet, they practiced writing one or two sentences on the tablet for 1 min before performing the CHES. The children then copied as much of a story as possible for 10 min. The story was selected from a literacy text for Grade 4 students. The primary author observed the pencil grasp patterns during the assessment. Each pencil grasp was identified as one of the four grasp patterns in Figure 1. If a grasp pattern differed from one of the four mature grasp patterns, it was described in terms of number and positioning of digits on the pencil barrel and labeled as *other*. Three children's pencil grasps were identified as other. The primary author also recorded whether the children switched grasp patterns during the assessment.

Data Handling and Analysis

All identifying information was removed from the writing samples, which were scored in random order for speed and quality by the primary author. A subset of samples was scored twice by the first rater to ascertain intrarater reliability for the quality of the writing samples. Intrarater agreement was 80% for quality scores. A second experienced rater completed grasp pattern categorization for a quarter of the sample and scored 10% of the samples for quality. The scores for quality were compared with those obtained by the primary author, and the percentage of agreement was determined. Interrater percentage of agreement was 80% for both quality scores and grasp classification.

Data analysis was completed using Matlab Version 7.9.0 (Mathworks, Natick, MA) and Statistical Analysis Software 9.2 programs (SAS Institute Inc., Cary, NC). Descriptive statistics on grasp distribution were completed. Only the sensors contacted by the fingers were used in the analysis. The sensor data were filtered with a low-pass Butterworth filter with a cutoff frequency of 15 Hz to eliminate the noise in the signal. The data from the pen and tablet were then calibrated separately. The following force parameters were derived from the calibrated data: mean grip and mean axial force, coefficient of variation (CV) of grip and axial forces (degree of variability in the grip forces), and change in means and CVs of both forces from CHES 1 to CHES 2 (δ).

To answer the primary question (i.e., Are there kinetic differences among grasps?), we performed three distinct analyses using multiple linear regression (MLR; Armitage, Beery, & Matthews, 2008) to examine the relationship between force parameters and (1) grasp pattern (DT, DQ, LT, LQ), (2) the number of fingers involved (tripod vs. quadrupod), and (3) the position of the thumb (lateral vs. dynamic). The MLR model controlled for handedness and gender because they may have an impact on handwriting performance. Because the sensors were replaced several times during the study, we also controlled for the pen. To address the second question (i.e., Is there a linkage between kinetic and functional differences?), we replicated these analyses for speed and legibility scores whenever significant effects of grasp, finger multiplicity, or thumb position were found.

Results

Participant Demographics and Distribution of Grasps

A sample of 120 children participated in the study. Data from 26 children were discarded because of technical issues with the sensors. An additional 17 children who switched between a lateral and a dynamic grasp pattern were also eliminated because they crossed groupings in the analysis. The 3 participants with immature, other grasp patterns were also removed. The final sample consisted of 74 children (average age = 9 yr, 11 mo), equally divided between boys and girls. The grasp distribution for the sample was DT, $n = 22$ (30%); DQ, $n = 12$ (16%); LT, $n = 19$ (26%); and LQ, $n = 21$ (28%).

Legibility of Writing and Speed

The CHES 1 average quality score was 56.89, and the average speed of writing was 54.6 LPM. Of the sample, 20% had CHES quality scores on the first administration of the assessment that were below the cutoff of 30. This fraction increased to 32% of CHES 2 quality scores after the 10-min copy task. The average quality score on CHES 2 was 43.10, which was statistically different from that of CHES 1, $t(73) = 7.44$, $p < .0001$. When the scores for the first and second assessments for individuals were compared, 10 children (13.5%) increased their quality scores after the 2-min copy task, an interesting result; however, the remainder of the children's scores decreased. The writing speeds on the CHES 2 and CHES 1 were not significantly different, $t(73) = -0.73$, $p = .467$; CHES 1 = 54.6 LPM, CHES 2 = 55.43 LPM.

Effect of Grasp on Force Parameters

Neither grasp pattern (DQ, DT, LT, LQ) nor the number of fingers on the pencil (tripod or quadrupod) had a significant effect on the force parameters for CHES 1, CHES 2, or change in force parameters between CHES 1 and CHES 2, $F(3, 63) \leq 2.57$, $p \geq .063$ for grasp pattern and $F(1, 63) \leq 0.64$, $p \geq .43$ for number of fingers on the pencil (Figures 2 and 3). Only thumb position (lateral or dynamic) had a significant relationship with mean grip force, mean axial force, and CV of axial force for CHES 1 (Figure 4). The mean grip force during CHES 1 was significantly higher for the lateral thumb position than for the dynamic thumb position, $F(1, 65) = 6.88$, lateral = 5.62 newtons (N), dynamic = 4.23 N, $p = .011$. The same was true for the mean axial forces, $F(1, 65) = 5.51$, lateral = 0.96 N, dynamic = 0.65 N, $p = .022$, and the CV of axial force was significantly different, $F(1, 65) = 6.24$, dynamic = 0.77

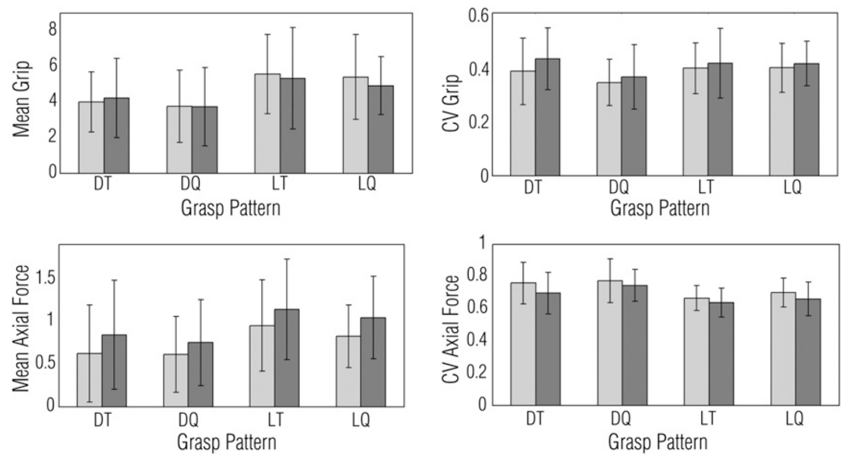

Figure 2. The effect of grasp on force for four grasp patterns.

Note. CV = coefficient of variation; DQ = dynamic quadrupod; DT = dynamic tripod; light gray = Children's Handwriting Evaluation Scale 1; dark gray = Children's Handwriting Evaluation Scale 2; LT = lateral tripod; LQ = lateral quadrupod.

N, lateral = 0.70 N, p = .015. For CHES 2, thumb position had a significant effect only on mean axial force (see Figure 4), which differed significantly between the lateral and dynamic grasp patterns, $F(1, 65) = 6.43$, lateral = 1.23 N, dynamic = 0.88 N, p = .014.

Thumb position did not have a significant effect on speed or legibility scores for both CHES 1 speed, $F(1, 65) = 0.90$, p = .346, and legibility, $F(1, 65) = 0.03$, p = .866, and CHES 2 speed, $F(1, 65) = 0.06$, p = .800, and legibility, $F(1, 65) = 0.06$, p = .812. In other words, kinetic differences were not associated with corresponding functional differences.

Effect of Grasp on Change in Mean Force From CHES 1 to CHES 2

We found no significant effects of grasp on the change in mean of grip and axial forces from CHES 1 to CHES 2 for any of the analyses: change in mean grip force, $F(3, 63) = 0.29$, p = .831; change in mean axial force, $F(3, 63) = 0.37$, p = .774; change in CV grip force, $F(3, 63) = 0.31$, p = .815; and change in CV axial force, $F(3, 63) = 0.64$, p = .593. This finding indicates that the effort involved in writing for >10 min affected the grasp patterns equally (see Figures 2–4).

Discussion

Distribution of Grasp Patterns

Three of the grasp patterns (DT, LT, and LQ) were almost equally prevalent; the DQ had the lowest prevalence in the sample. Other research has found similar results (Dennis & Swinth, 2001; Koziatek & Powell, 2003; Schwellnus et al., 2012), which further supports the need to determine whether these grasp patterns can be treated as kinetically equivalent.

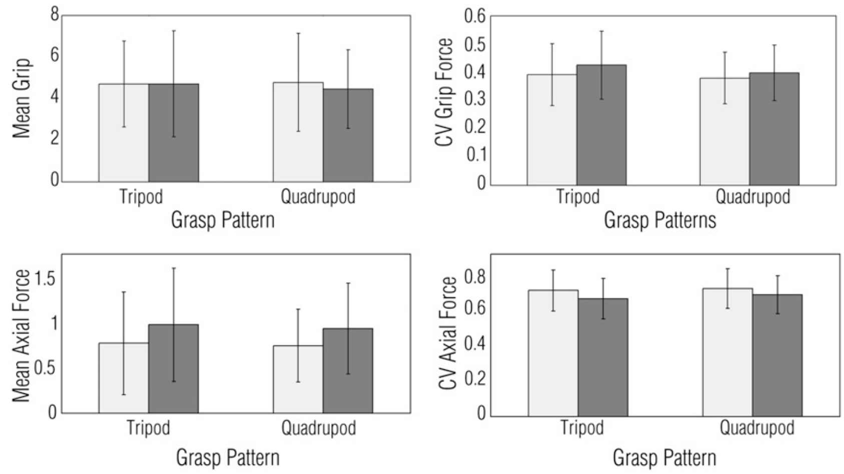

Figure 3. The effect of grasp on force: Quadrupod versus tripod.

Note. CV = coefficient of variation; light gray = Children's Handwriting Evaluation Scale 1; dark gray = Children's Handwriting Evaluation Scale 2.

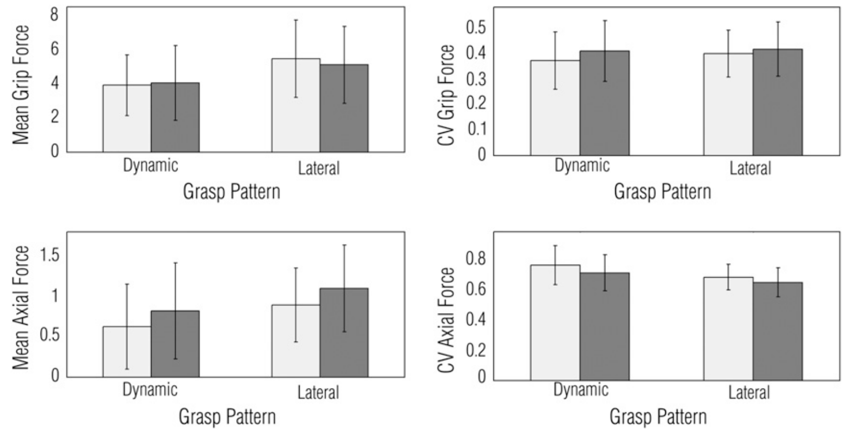

Figure 4. The effect of grasp on force: Dynamic versus lateral grasp.

Note. CV = coefficient of variation; dynamic = fingers in opposition; lateral = fingers adducted; light gray = Children's Handwriting Evaluation Scale 1; dark gray = Children's Handwriting Evaluation Scale 2.

Legibility and Speed of Writing

The legibility scores for CHES 1 indicated that 20% of the sample had dysgraphic writing, which is higher than that found by Overvelde and Hulstijn (2011) but is in line with other previous research findings (Graham et al., 1998; Smits-Engelsman et al., 2001). After the 10-min copy task, the percentage of children with dysgraphic writing increased to 32%, a result indicating that the task did fulfill its purpose of increasing the participants' effort. Interestingly, 10 participants (13%) increased their legibility score for CHES 2; four dysgraphic writers actually increased sufficiently to reclassify themselves as proficient. These children may have needed a considerably longer copy task to affect the quality of their writing to the same degree. An alternative explanation from a motor learning perspective is that these children found writing on the tablet to be an unfamiliar task and had some difficulty controlling the pencil during CHES 1, and that after the copy task, they became more familiar with the experience and could better control the quality of their writing (Engel-Yeger & Rosenblum, 2010). A third explanation is that instead of classifying children as dysgraphic solely on legibility criteria, rate information is needed to reduce Type 1 error.

Grip and Axial Forces

The grip and axial forces were not significantly different among the four grasp patterns when compared with each other individually or when compared by the number of fingers on the barrel of the pencil. The differences in the mean grip force and the mean and variability of the axial forces of the four grasp patterns were only significant when the grasps were classified by thumb position. A larger amount of force was exerted on the barrel of the pencil when the thumb was adducted and placed over rather than in opposition to the index finger only during CHES 1; this difference did not occur during CHES 2. The difference may be the result of the need to increase digit force to compensate for the lack of thumb opposition when the tripod or quadrupod is lost (Soechting & Flanders, 2008). That being said, the difference in mean grip force occurred only during CHES 1, which, because no difference was found in legibility or speed of writing among the four grasp patterns, corroborates previous results of similarity in function of grasp patterns (Koziatek & Powell, 2003; Schwellnus et al., 2012). Further research could investigate a similar protocol with an even longer copy task to determine whether these results hold for older students who may be required to write >14 min.

The variability of grip forces was not significantly different among any of the grasp patterns in any of the comparisons, suggesting that although the lateral grasps may appear to have lesser degrees of small movements than the dynamic grasps at the distal finger joints, the variability of the forces is not different for any of the grasp patterns. A higher variability of grip force has been found to be linked to greater legibility (Falk et al., 2010). The variability of the axial force was significantly different for CHES 1 but not for CHES 2. Engel-Yeger and Rosenblum (2010) found that with increased writing speed, which occurred in CHES 2, distal muscle variability decreased, indicating fixing of the joints to write faster. Consistent with this finding, the CV of the grip forces in this study did not change from CHES 1 to CHES 2; however, axial force varied more during CHES 1. Fatigue may possibly have decreased the motor coordination and therefore movement coordination, and to compensate for this lack of control, the participants may have decreased the variability of the grip force by fixing the distal joints (Aune, Ingvaldsen, & Ettema, 2008) and potentially writing with greater mean axial pressure. Another possible explanation is that the CHES 1 results may have been transient as the children accommodated to writing on the tablet. This explanation is supported by the results of a 2010 study that found that children used previous knowledge of a handwriting task to improve their performance (Engel-Yeger & Rosenblum, 2010).

Grip and axial forces were not significantly different between CHES 1 and CHES 2, suggesting that the forces involved in the four grasp patterns are equally affected by the extended copy task. The children did write faster on CHES 2, and an increase in speed has been found when writing for longer periods (Dennis & Swinth, 2001; Kushki, Schwellnus, Ilyas, & Chau, 2011). When writing faster, children may use increased force or have increased variability in axial force, behaviors that have previously had the impact of reducing legibility (Engel-Yeger & Rosenblum, 2010; Harris & Rarick, 1957, 1959); however, we did not find this reduction of legibility in the current study.

Implications for Occupational Therapy Practice

The four commonly occurring pencil grasps seem to be more equivalent than different in terms of grip kinetics. Even with increasing use of technology, the continued teaching and mastery of handwritten work has been found to be beneficial for dissociation of reversals and improved reading. As a result, it is important to continue to refer children with handwriting difficulties to occupational therapists to assist with the mastery of this key skill; however, referrals for children solely for an "incorrect" pencil grasp pattern may not be necessary if the child has grade-appropriate functional writing. The focus of intervention should shift to improving the speed and formation of letters to enhance legibility rather than to alter the grasp pattern.

Limitations, Future Work, and Conclusions

Our findings further support the equivalence of the four mature pencil grasps for functional writing, even after an extended copy task. The kinetics, speed, and legibility of writing were not different among children who used four different types of grasp after 10 min of writing. Only when the grasps were grouped according to the thumb position did any significant differences in mean grip and axial forces arise; however, these changes in force did not affect the speed or legibility of the writing.

One limitation of the study is that the volunteer sample was recruited from middle- to upper-middle-class neighborhoods of a metropolitan city and thus may not have been representative of the general population. In addition, the final sample size was a modest 74. With the students all using manuscript writing, a nonnormative scoring cutoff for legibility was derived and rendered the speed data usable only as raw scores. Thus, our demarcation of the sample ought to be interpreted with caution. The protocol involved writing on the tablet, which may have been unfamiliar to some participants; however, the initial practice time and the proliferation of pen-enabled gaming devices would have reduced the novelty of tablet-based writing. Last, the 10-min copy task may not have been sufficient to fatigue all participants. Nonetheless, this extended writing task did alter perceived effort scores.

At the time of this study, no standardized handwriting assessment for manuscript writing for Grade 4 children was available. If the use of manuscript in higher grades is indeed a prevalent practice, the development of an appropriate handwriting assessment would be necessary. Future research should also further study the kinetics of static or immature grasps to determine whether the writing forces are affected by the loss of dynamic movement. ▲

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