Hand Strength, Handwriting, and Functional Skills in Children With Autism

Michele L. Alaniz, Eleanor Galit, Corina Isabel Necesito, Emily R. Rosario

OBJECTIVE: To establish hand strength development trends in children with autism and to investigate correlations between grip and pinch strength, components of handwriting, and functional activities in children with and without autism.

METHOD: Fifty-one children were divided into two groups: typically developing children and children on the autism spectrum. Each child completed testing for pinch and grip strength, handwriting legibility, pencil control, and independence in functional activities.

RESULTS. The children with autism followed the same strength development trends as the typically developing children. Grip strength correlated with pencil control in both groups and with handwriting legibility in the typically developing children but not in the children with autism. Grip and pinch strength correlated with independence with functional activities in both groups.

CONCLUSION. This study provides evidence that grip and pinch strength are important components in developing pencil control, handwriting legibility, and independence with functional fine motor tasks.

Dysgraphia and delays in functional living skills are well established in the literature as impairments affecting children on the autism spectrum (Abu-Dahab, Skidmore, Holm, Rogers, & Minshew, 2013; Frith, Morton, & Leslie, 1991; Fuentes, Mostofsky, & Bastian, 2009; Kushki, Chau, & Anagnostou, 2011). As part of the evaluation and treatment process, pinch and grip strength are often measured (Engel-Yeger & Rosenblum, 2010; Ertem et al., 2005) because of the assumption of a correlation between strength and occupational performance. Previous studies have established that children with autism have weaker grip strength than typically developing children (Abu-Dahab et al., 2013; Hardan, Kilpatrick, Keshavan, & Minshew, 2003; Williams, Goldstein, & Minshew, 2006). In this study, we sought to investigate the correlation between grip and pinch strength and functional performance in typically developing children and children on the autism spectrum. We also sought to establish developmental trends for pinch and grip strength in children with autism.

Strength and Handwriting

Pinch and grip strength may influence performance in a variety of childhood tasks. The fine motor task that dominates a child’s school day is handwriting. Children on the autism spectrum often have poor handwriting legibility (Fuentes et al., 2009), which hinders their academic achievement (Cahill, 2009; Feder & Majnemer, 2007). Handwriting is a complex task, and many underlying skills contribute to the development of legible penmanship. Handwriting
remediation is as complex as the skill itself, and there is quite a bit of diversity in the activities included in a handwriting remediation program.

Most occupational therapy practitioners report using an eclectic approach (Feder, Majnemer, & Synnes, 2000; Woodward & Swinth, 2002) that blends sensory feedback, direct handwriting instruction, and fine motor development into a comprehensive handwriting intervention (Case-Smith, 2002; Peterson & Nelson, 2003). Within this eclectic approach, practitioners often include activities that target the development of pinch strength. In fact, research supports the practice of measuring pinch strength as part of the evaluation process for dysgraphia (Engel-Yeger & Rosenblum, 2010). Despite this common practice, research does not provide consistent, reliable information on pinch strength norms for children, and no correlation between pinch strength and handwriting legibility has been established for children with disabilities.

Research instead has focused primarily on evaluating the effectiveness of a variety of handwriting remediation techniques (Denton, Cope, & Moser, 2006). Research has also focused on determining the relationship between handwriting and underlying deficits such as grasp pattern (Falk, Tam, Schwellnus, & Chau, 2010), eye-hand coordination, visuomotor integration, and in-hand manipulation (Case-Smith, 2002; Cornhill & Case-Smith, 1996; Dennis & Swinth, 2001; Feder & Majnemer, 2007). However, little research has addressed the correlation between pinch and grip strength and handwriting performance. Engel-Yeger and Rosenblum (2010) assessed the correlation between tripod pinch strength (palmar pinch) and dysgraphia and found that deterioration in tripod strength was associated with a significant deterioration in handwriting processes. The study sample, however, included students with at least average intelligence and no neurological or perceptual–motor problems. No research to date has examined the association of pinch and grip strength with handwriting in children with autism.

Strength and Functional Activities

Whereas handwriting is an important childhood task in the academic environment, self-care activities are an important childhood task in the home environment. Many self-care skills, such as manipulating fasteners, opening packages, and tying shoes, require pinch strength and fine motor control. Limited research has investigated the relationship between pinch and grip strength and functional performance. Li-Tsang (2003) found that dexterity, not hand strength, correlated with functional deficits and fine motor delays in children with neurological motor dis-orders. Studies have established that children with autism often experience delays in achieving independence with daily living skills (Green & Carter, 2014; Jasmin et al., 2009; Liss et al., 2001) and that these delays correlate with age, IQ, and language and sensorimotor skills. These studies did not assess hand strength to determine whether a link exists between delays in functional independence and grip and pinch strength.

Pinch and Grip Strength Norms and Trends

Pinch and grip strength norms have been the subject of study for several decades. In the mid-1980s, researchers began to use a standardized approach to gather strength measurements that included a positioning protocol recommended by the American Society of Hand Therapists (ASHT; Fess & Moran, 1981). The ASHT recommended that the participant be seated with feet flat on the floor and a 90° bend in the hips, the shoulder adducted and neutrally rotated, the elbow flexed to 90°, the forearm in neutral position, the wrist between 0° and 90° and ulnar deviation between 0° and 15°, and the measurement tool supported by the examiner. They also recommend that three consecutive trials be measured and the mean of the three trials reported.

When examining the research from 1975 to 2014 to determine pinch strength norms for children, we found only six studies that included a reliable measurement tool; followed the ASHT protocol; and gathered pertinent information about gender, age, and hand dominance (Bear-Lehman, Kafko, Mah, Mosquera, & Reilly, 2002; Butterfield, Lehnard, Loovis, Coladarci, & Saucier, 2009; Mathiowetz, Wiemer, & Federman, 1986; Molenaar, Selles, Schreuders, Hovius, & Stam, 2008; Surrey et al., 2001; Yim, Cho, & Lee, 2003). Studies have firmly established that grip and pinch strength increase with age (Ager, Olivett, & Johnson, 1984; Bear-Lehman et al., 2002; Butterfield et al., 2009; De Smet & Decramer, 2006; Imrhan & Loo, 1989; Lee-Valkov, Aaron, Eladoumikdachi, Thornby, & Netscher, 2003; Mathiowetz et al., 1986; Molenaar et al., 2008; Surrey et al., 2001; Yim et al., 2003). Evaluations of other trends in strength development have yielded inconsistent findings. The influence of hand dominance and gender on hand strength development is under debate.

Research is almost completely silent on the topic of pinch and grip strength norms in children with disabilities. Broadhead (1975) indicated that students with disabilities are able to generate statistically reliable scores. The grip scores for children with disabilities generally followed the same trends identified in the population as
a whole; however, a standardized positioning protocol and measurement tool with proven reliability were not used. Recent studies found that children with autism have lower grip strength than their typically developing peers (Abu-Dahab et al., 2013; Hardan et al., 2003; Kern et al., 2013; Williams et al., 2006). However, these studies do not detail factors such as hand dominance and gender or include pinch measurements in the findings. Moreover, they do not report the positioning protocol followed when obtaining strength measurements.

Research Questions

In this study, we evaluated the relationship between grip and pinch strength and handwriting and independence with functional activities in typically developing children and children on the autism spectrum. We also sought to establish developmental trends for pinch and grip strength in children with autism. This study sought to answer the following research questions:

- Does grip and pinch strength development in children with autism follow the same trends as in typically developing children?
- Does grip and pinch strength correlate with handwriting legibility in typically developing children and children with autism?
- Does grip and pinch strength correlate with pencil control in typically developing children and children with autism?
- Does grip and pinch strength correlate with independence with functional activities in typically developing children and children with autism?

Method

Participants

Typically developing children \((n = 24)\) and children on the autism spectrum (as reported by a physician or parent; \(n = 27\)), aged 4–10 yr old, were included in the study if they were able to understand and follow directions and if they were able to complete the majority of the testing. Children who were unable to complete the majority of the testing because of severe visual, cognitive, or motor impairments were excluded (2 children were excluded for this reason). None of the participants in the autism group were reported to have Rett syndrome or childhood disintegrative disorder; children with pervasive developmental disorder not otherwise specified were included.

Participants with autism were recruited from among the clients currently receiving therapy services at an outpatient pediatric clinic in Southern California. Flyers were posted at the clinic and given to parents of current clients. In addition, clinicians recommended participation in the study when they felt it was appropriate for their client. Typically developing participants were recruited using flyers and emails to hospital employees; therefore, the sample of typically developing children was composed primarily of employees’ children. After approval from the institutional review board, full consent and assent were obtained for all children participating in the study. Participants were divided into two groups for analysis: typically developing children and children on the autism spectrum.

Instruments

Grip and pinch strength were measured using a Sammons Preston Jamar hand dynamometer and pinch meter (Patterson Medical, Warrenville, IL). These instruments were calibrated on an annual basis to ensure proper measurement. The Beery–Buktenica Developmental Test of Visual–Motor Integration (VMI) Motor Coordination subtest was used to assess pencil control (Beery & Beery, 2004). The VMI is a standardized test used for both research and clinical purposes in children aged 2–18 yr. The VMI has been used extensively in the United States and other countries and demonstrates high psychometric properties (test–retest reliability \(r = .92\), Cronbach’s \(\alpha = .86\), construct validity = .84; Beery & Beery, 2004). The Evaluation of Children’s Handwriting (ETCH; Amundson, 1995) was used to measure handwriting legibility. The ETCH has shown good test–retest reliability \((r = .85–.90)\) and validity \((r = .86;\) Diekema, Deitz, & Amundson, 1998; Feder & Majnemer, 2007).

A functional questionnaire was designed for this research study based on activities children aged 4 yr and older could complete. A total of 27 items in four domains assessed dressing, mealtime, grooming, and miscellaneous activities. Caregivers rated their child’s independence in functional skills requiring pinch or grip strength (e.g., opens a twist-off bottle top with closed seal, tears open a small snack, manipulates snaps) on a 5-point scale \((4 =\) independent, \(3 =\) completes with encouragement, \(2 =\) needs minimal assistance, \(1 =\) needs maximum assistance, and \(0 =\) unable to complete).

Procedure

Participants were tested at the outpatient pediatric clinic. Right and left grip and pinch strength were measured consecutively using the ASHT positioning protocol. Effort and understanding were documented for each participant on a 3-point scale \((1 =\) none, \(2 =\) poor, \(3 =\) average) during...
Grip and pinch strength were assessed with the VMI Motor Coordination subtest. Grip strength correlated with handwriting legibility in the autism group, $F(1, 32) = 5.8, p = .02$, and the typically developing group, $F(1, 32) = 3.5, p = .07$, but not within the autism group; however, it did correlate within the autism group ($p = .04$).

Hand Strength and Pencil Control
In the sample as a whole, grip strength correlated with pencil control as measured by the VMI Motor Coordination subtest. Grip strength correlated with pencil control in the typically developing group, $F(1, 22) = 8.1, p = .008$, and the autism group, $F(1, 25) = 7.9, p = .01$. Pinch strength did not correlate with pencil control for the sample as a whole or within the typically developing or autism groups.

Grip and Pinch Strength and Handwriting
In participants who were able to complete the ETCH ($n = 32, 63\%$), grip strength correlated with handwriting legibility using a mean percentage of legibility for Upper Case, Lower Case, and Numbers, $F(1, 30) = 10.9, p = .002$. Grip strength correlated with handwriting legibility in the typically developing group ($n = 16$), $F(1, 14) = 6.1, p = .03$, but not in the autism group ($n = 16$), $F(1, 14) = 3.2, p = .09$; see Figure 2. Pinch strength did not correlate with handwriting in either group.

Grip and Pinch Strength and Functional Abilities
Grip strength and lateral, palmar, and tip pinch strength correlated with functional activities when examining the
sample as a whole. When looking at the typically developing and autism groups separately, however, we observed a significant relationship between only grip strength and lateral pinch strength and functional activities (Figure 3). The functional activities most significantly correlated with grip strength included tears open a small snack, \( F(1, 49) = 6.6, p = .02 \); opens twist-off bottle top with closed seal, \( F(1, 49) = 13.1, p = .004 \); cuts food with knife, \( F(1, 49) = 5.2, p = .04 \); puts straw in juice box, \( F(1, 49) = 9.3, p = .01 \); takes cap off toothpaste, \( F(1, 49) = 5.7, p = .038 \); squeezes toothpaste on toothbrush, \( F(1, 49) = 8.2, p = .01 \); turns key to unlock door, \( F(1, 49) = 8.7, p = .01 \); and turns doorknob to open door, \( F(1, 49) = 6.6, p = .02 \).

Discussion

This study investigated the correlation between grip and pinch strength and proficiency in functional activities, including handwriting legibility and functional tasks, in children with and without autism aged 4–10 yr. It also sought to establish grip and pinch strength trends in children with autism. Children with autism followed the same established developmental trends in strength as the typically developing children, although their strength scores were lower than their typically developing peers in all measurements. Grip strength correlated with pencil control in both groups and with handwriting legibility in the typically developing children but not in the children with autism. Grip and pinch strength correlated with independence in functional activities in both groups.

Grip and Pinch Strength Trends

Our participants, including the children with autism, followed the grip and pinch strength trends established in the literature (Ager et al., 1984; Bear-Lehman et al., 2002; Butterfield et al., 2009; De Smet & Decramer,

<table>
<thead>
<tr>
<th>Age Category</th>
<th>Sample Size</th>
<th>Grip Strength</th>
<th>Tip Pinch Strength</th>
<th>Lateral Pinch Strength</th>
<th>Palmar Pinch Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TD ASD</td>
<td>TD ASD</td>
<td>TD ASD</td>
<td>TD ASD</td>
<td>TD ASD</td>
</tr>
<tr>
<td>4–6 yr</td>
<td>8 11</td>
<td>16.5 ± 1.2</td>
<td>2.1 ± 0.3</td>
<td>5.1 ± 0.6</td>
<td>3.2 ± 0.6</td>
</tr>
<tr>
<td>6–8 yr</td>
<td>10 11</td>
<td>21.1 ± 1.7</td>
<td>5.0 ± 1.5</td>
<td>6.5 ± 0.6</td>
<td>5.7 ± 0.6</td>
</tr>
<tr>
<td>8–10 yr</td>
<td>6 5</td>
<td>30.5 ± 1.4</td>
<td>5.6 ± 0.9</td>
<td>8.9 ± 0.6</td>
<td>8.4 ± 1.2</td>
</tr>
</tbody>
</table>

Note. ASD = children with autism spectrum disorder; TD = typically developing children.

Figure 1. (A) Grip strength and pinch strength—(B) tip, (C) lateral, and (D) palmar—increase with age.

Note. ASD = children with autism spectrum disorder; TD = typically developing children. 
*p < .05.
We found that children with and without autism grew stronger with age. In addition, we did not observe a significant difference between boys and girls in their pinch and grip strength scores; this finding is still debated in the literature (Ager et al., 1984; Bear-Lehman et al., 2002; De Smet & Decramer, 2006; Imrhan & Loo, 1989; Mathiowetz et al., 1986; Molenaar et al., 2008; Yim et al., 2003). Also unclear based on the current literature is the impact of hand dominance on strength in children. Our findings were consistent with those of studies that found a non-significant association between hand dominance and pinch and grip strength (Ager et al., 1984; Bear-Lehman et al., 2002; Butterfield et al., 2009; De Smet & Decramer, 2006; Lee-Valkov et al., 2003; Mathiowetz et al., 1986).

A finding unique to this study is the establishment of new trends for children with autism. Our findings indicate that no statistically significant difference exists in pinch strength between typically developing children and children with autism. We found a trend, however, toward increased grip strength in the typically developing children compared with the children with autism. The divergence between the groups increased with age, indicating that the gap between typically developing children and children with autism widens as children grow older. A larger sample size is needed to more clearly define this relationship.

Also of note, we found that children with autism were less reliable in producing consistent scores across three trials during the strength measurements; 43% of the children with autism, compared with 20% of the typically developing children, had a CV greater than 20%. Characteristics inherent in the autism diagnosis, such as communication delays, social delays, and stereotypical behaviors, likely interfered with the children’s ability to produce consistent results.

Both right and left grip strength correlated with amount of effort in the sample as a whole; in other words, the more effort put forth, the higher the grip strength scores. However, effort did not correlate with strength in the typically developing or autism groups individually. This finding may indicate that although the amount of effort put forth during testing had an influence on strength scores, it was a minor influence.

Right and left grip strength also correlated with comprehension of testing directions in the sample as a whole. For the typically developing group, however,
direction comprehension did not correlate with strength; these children almost always seemed to understand the directions. In contrast, direction comprehension did correlate with strength in the children with autism. Because communication delays are intrinsic to the diagnosis of autism, these children are particularly vulnerable to not understanding directions, compromising their ability to reliably participate in strength testing (American Psychiatric Association, 2000).

**Correlations Between Functional Measures and Hand Strength**

Previous studies have established the correlation between pencil control and handwriting legibility (Cornhill & Case-Smith, 1996). Our study sought to establish a correlation between hand strength and pencil control measured using the VMI Motor Coordination subtest. For the sample as a whole, grip strength correlated with $T$ scores on the VMI Motor Coordination subtest, indicating that the stronger the grip strength, the better the pencil control. This correlation was observed in both the typically developing and autism groups.

Interestingly, pinch strength did not correlate with pencil control. We hypothesize that this finding is attributable to the sensitivity of the instruments used to measure grip and pinch strength. We collected strength data using a manual-read, rather than digital, dynamometer and pinch gauge. To maintain consistency throughout the research, if the measurement fell between whole numbers, the score was rounded down to the nearest whole number. Pinch strength scores are particularly susceptible to low sensitivity because the numbers are so small. Because we did observe a correlation between grip strength and pinch strength, however, pinch strength might also have correlated with pencil control were it not for the limitations of the sample size and measurement sensitivity.

The relationship between strength and handwriting legibility was assessed using the ETCH. In the sample as a whole, grip strength correlated with handwriting legibility. The typically developing children demonstrated a correlation between strength and legibility, a finding that agrees with previous work in which a correlation was observed between tripod pinch strength and dysgraphia in typically developing children (Engel-Yeger & Rosenblum, 2010). However, the autism group did not demonstrate a correlation between hand strength and handwriting legibility. Contributing to this finding may be the fact that only 78% of our participants with autism who were eligible to complete the ETCH were able to complete the ETCH testing, whereas 100% of the typically developing participants who were eligible to complete the ETCH did so.

Moreover, handwriting is a complex skill, and many components influence handwriting development. Cognitive demands, visual–perceptual demands, and visual–motor integration, along with fine motor strength and development, all influence handwriting development. Our findings indicate that although hand strength does influence handwriting legibility, other, more salient factors also influence legibility, making hand strength less critical in children with autism.

Finally, we examined the relationship between functional abilities and grip and pinch strength. To do this, we developed a questionnaire for this research asking the parents to rate their child’s independence in a variety of fine motor functional tasks. In the sample as a whole, functional abilities correlated with lateral, palmar, and tip pinch strength in both the right and left hands. A variety of correlations emerged in examining the groups separately. In the typically developing group, nondominant grip strength and dominant palmar pinch strength correlated with independence in functional tasks. In the autism group, right and left grip strength, right and left lateral pinch strength, and nondominant palmar pinch strength correlated with one another. To further define the functional activities that more strongly correlated with grip and pinch strength, we performed a discriminant analysis (see Table 1). Grip and pinch strength were strongly correlated with independence in functional activities in both groups.

**Study Limitations**

The primary limitation of this study is the sample size, particularly when the sample is divided by sex, age, and diagnosis. In addition, because only 78% of the children with autism were able to complete the ETCH, the sample size for this analysis was even further reduced. Although we are able to draw some conclusions regarding trends and relationships, we are limited in making more specific statements about gender differences and age-related changes. In addition, we believe that the pinch strength data were limited by the sensitivity of the measurement tool. Because we were not able to record values to a decimal place, our analysis of pinch strength was limited. However, because the measurement tool we used is commonly used clinically, our pinch data carry some clinical validity. We were also limited in our interpretation of the relationship between grip strength and pencil control. Although children with visual impairments were excluded, we did not complete any visuoperceptual testing. Therefore, when examining the results regarding
pencil control, we were not able to rule out the possible contribution of visuoperceptual deficits.

Implications for Occupational Therapy Practice

The findings of this study have the following implications for occupational therapy practice:

- The amount of effort put forth during testing has a minor influence on pinch and grip strength measurements in typically developing children and children with autism.
- Whether children understand the directions is important when taking grip and pinch strength measurements, particularly with children who have autism. Researchers should consider calculating the CV and either dropping outlier scores or adding trials to get closer to a true score.
- Grip strength correlates with pencil control.
- Grip strength does not correlate with handwriting legibility in children with autism.
- Grip strength correlates with handwriting legibility in typically developing children.
- Grip and pinch strength correlate with functional abilities. ▲

Acknowledgments

The authors thank Dr. Loverso and the Casa Colina Board of Directors, Cindy Sendor, the therapists in the children’s department (Lacy Wright, Sarah Yun, Kristin Horn, and Yovana Guzman), and the Casa Colina Hospital and Centers for Healthcare Foundation for supporting this research. We also thank Brianna Bentley and Betsy Diaz for their involvement in study recruitment and testing.

References


