Predictors of handwriting in children with Autism Spectrum Disorder

Abstract

During writing, perceptual, motor, and cognitive processes interact. This study explored the predictive value of several factors on handwriting quality as well as on speed in children with Autism Spectrum Disorder (ASD). Our results showed that, in this population, age, gender, and visual-motor integration significantly predicted handwriting quality, whereas age, reading abilities, and fine motor coordination had an impact on handwriting speed. These results indicate that, although reading abilities are often overlooked, handwriting remediation in children with ASD should tackle reading skills as well.

Key words: handwriting, Autism Spectrum Disorders, predictors

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1. Introduction

Handwriting is a complex task in which perceptual, motor, and cognitive processes interact (Berninger, Mizokawa, & Bragg, 1991; Graham & Weintraub, 1996; Tseng & Cermak, 1993), implying that, when learning to write, skills in several domains need to be mastered. Due to its complexity, a substantial part of children struggle to develop proficient handwriting (Karlsdottir & Stefansson, 2002; Smits-Engelsman & Van Galen, 1997). In the Dutch-speaking part of Belgium, Flanders, children must be able to copy texts in polished handwriting at the end of primary school (Vlaams Ministerie van Onderwijs en Vorming, 2010) and the way this aim has to be reached is determined by each school board itself.

In certain clinical syndromes, a higher prevalence of handwriting difficulties compared to typically developing (TD) children has been reported. Lately, it has become increasingly obvious that children with Autism Spectrum Disorder (ASD) encounter serious writing difficulties. Several studies have found that, during a copy task, children and adolescents with Asperger syndrome or ASD produce fewer legible letters and words, write with an overall lower quality, and make more errors regarding letter alignment, size, and formation than TD children and adolescents (Fuentes, Mostofsky, & Bastian, 2009, 2010; Myles et al., 2003). During free writing as well, just slightly more than half of the words produced by two children with Asperger syndrome were legible (Henderson & Green, 2001). On the other hand, no significant difference in legibility was found between children with ASD and TD children in the study of Cartmill, Boccthy, Rodger, and Medst (2009). With respect to writing speed, children and adolescents with Asperger syndrome or ASD appeared not to write slower than TD children (Cartmill et al., 2009; Fuentes et al., 2009, 2010), although the two children with Asperger syndrome examined by Henderson and Green (2001) did produce fewer letters in one minute than what was expected at their age.

Children who are unable to master sufficient handwriting skills are often referred to physiotherapists, occupational, or speech therapists, because without extra help, they do not improve sufficiently (Smits-Engelsman & Van Galen, 1997). It is important to remediate handwriting difficulties because of their negative impact on school records (Briggs, 1980; Hughes, Keeling, & Tuck, 1983). In order to treat handwriting problems adequately, practitioners need to know which factors contribute to handwriting difficulties.

First of all, the handwriting of boys and girls differs substantially. In fact, the dissimilarities are so prominent that one can easily predict a writer's gender by the written output (Burr, 2002). The overall impression from previous studies is that girls generate handwriting of higher quality (Berninger & Fuller, 1992; Graham, Weintraub, Berninger, & Schafer, 1998; L. Hamstra-Bletz & Blöte, 1993; Ziviani & Elkins, 1984). More specifically, they form and align letters more adequately and write smaller (Fuentes, et al., 2009; Ziviani & Elkins, 1984). Regarding writing speed, no consensus has been reached. Several studies have observed a higher writing rate in girls (Berninger & Fuller, 1992; Graham et al., 1998; Ziviani & Elkins, 1984), while others have not (Rueckriegel et al., 2008; Ziviani & Watson-Will, 1998). Also in adulthood, a difference exists between women and men: the former write more legibly and faster (Van Drempt, McCluskey, & Lannin, 2011).

Regarding hand preference, the statement that neither legibility nor writing speed differs between left- and right-handers is generally been accepted (Graham & Weintraub, 1996).

Throughout maturation, handwriting speed increases before reaching a plateau in grade 9 since at that point, children's writing speed approximates the level of adults (Graham et al., 1998; Rueckriegel et al., 2008). Likewise, handwriting legibility also improves during primary school, mainly during the later years (Graham et al., 1998), although Ziviani and

Elkins (1984) have already observed a significant improvement in letter formation, letter size, horizontal alignment, and spacing in younger students.

As mentioned above, in order to reach the level of skilled handwriting, several perceptual, motor, and cognitive processes need to be mastered. Below, previous research, identifying predictive factors of handwriting, is summarized.

An important variable during writing, particularly when learning to form letters (Weintraub & Graham, 2000) or copying text (Cornhill & Case-Smith, 1996), is visual-motor integration. Beery, Buktenica, and Beery (2004) defined this as the ability to coordinate visual perception with finger movements and developed the Developmental Test of Visual-Motor Integration, in which participants are instructed to copy geometric shapes, in order to assess this skill. This test is used by most researchers who examine visual-motor integration abilities and was applied in all of the handwriting studies recited below unless otherwise mentioned. Visual-motor integration skills correlate significantly with handwriting quality in primary school children, TD kindergarten children, TD 5th-graders, and in 10-year-old clumsy children, half of them experiencing writing difficulties (Daly, Kelley, & Krauss, 2003; Maeland, 1992; Overvelde & Hulstijn, 2011; Preminger, Weiss, & Weintraub, 2004). According to Bumin and Kavak (2008), also in primary school children with Cerebral Palsy (CP), visual-motor control is associated with handwriting legibility as well as with rate. In this study, visual-motor integration skills were not only measured by the accuracy which geometric forms were copied with, but also by the level of precision which a two-dimensional model was reproduced and a clock was drawn with. In TD children, teachers' ratings of writing abilities were also reported to relate to visual-motor integration (Kulp, 1999). Barnhardt, Borstig, Deland, Pham, and Vu (2005) observed that children with poor visual-motor coordination made more positioning errors while writing letters and words compared to children with competent integration skills. A strong relationship between visual-motor control and spacing of letters and words was also found in children with CP (Bumin & Kavak, 2008). Furthermore, visual-motor integration was reported to be a significant predictor of handwriting speed in slow writers (Tseng & Chow, 2000), of handwriting quality in children with handwriting difficulties and TD second-graders (Kaiser, Albaret, & Doudin, 2009; Volman, van Schendel, & Jongmans, 2006), of handwriting legibility in children with Attention Deficit Hyperactivity Disorder (ADHD) and children with learning and/or behavioural problems (Brossard-Racine, Majnemer, Sheveli, Snider & Bélanger, 2011; Klein, Guiltner, Sollereder, & Cui, 2011), and of writing performances in first-grade children regardless of their level of handwriting (Cornhill & Case-Smith, 1996). Finally, in TD kindergarten children, the ability to copy letters was reported to increase as integration abilities improved, indicating that the level of visual-motor integration is a marker of handwriting readiness (Daly et al., 2003; Weil & Amundson, 1994). Important to bear in mind is that the relationship between these skills and quality of handwriting diminishes with age, implying that in older children, visual-motor integration problems are no (longer) the main cause of handwriting dysfunctions (Overvelde & Hulstijn, 2011).

Rather than poor visual-motor integration skills, deficient visual perceptual abilities per se can also contribute to handwriting dysfunctions. Several areas of visual perception appear to influence handwriting, e.g., visual closure to identify whether letter forms are complete, visual spatial relations to align letters and words correctly, form constancy to discriminate between similar letters and words, and visual memory to sequence letters adequately (Amundson & Weil, 1996, as cited in Feder & Majnemer, 2007, p. 314). Research findings on the impact of visual perception on handwriting are however ambiguous. In a study by Tseng and Chow (2000), visual memory was identified as a significant predictor of writing speed in slow writers. Additionally, they found that two other domains, namely visual discrimination and closure, were of minor interest when copying a familiar text. In children with learning and/or behavioural problems, Klein et al. (2011) found that visual perception significantly predicted writing legibility during a copy task. In first-graders however, the total score on a test of visual perception did not differ significantly between good and poor writers (Yost & Lesiak, 1980). Furthermore, the level of visual perception did not relate to either handwriting speed or quality in second- and third-graders with either good or poor writing skills (Volman et al., 2006).

Motor functioning is another component which influences writing abilities in children. According to L. Hamstra-Bletz and Blöte (1993), problems of dysgraphic writers are related to a lack of fine motor control. Furthermore, unimanual dexterity is stated to explain 21% of variance in handwriting legibility in TD children (Volman et al., 2006). Additionally, in a study by Tseng and Chow (2000), fine motor skills accounted for 9.95% of the variance in writing speed in children who produced an adequate printing rate. This association between speed and upper limb expertise was also observed in TD children (Bumin & Kavak, 2008) and in children with learning and/or behavioural problems (Klein et al., 2011).

Finally, on the cognitive domain, previous studies have indicated that IQ and reading abilities are related to writing mechanics. A positive correlation between verbal IQ and writing speed as well as a negative relationship between total IQ and handwriting errors were observed (Berninger, et al., 1992; McKay & Neale, 1985). Biemiller, Regan, and Gang (1993, as cited in Graham & Weintraub, 1996, p. 34) found a positive correlation between writing fluency and reading speed. Additionally, Kandel, Soler, Valdois, and Gros (2006) found that children with the best reading levels took less time to write words and wrote more fluently. Shared cognitive processes or structures and knowledge representations may underlie the relationship between reading and writing (Fitzgerald & Shanahan, 2000; Shanahan, 1984). Nicolson and Fawcett (2009) pointed out that dysgraphia and dyslexia are possibly both caused by impairments in procedural learning circuits involving the cerebellum.

One might wonder which of these factors causes poor handwriting in children with ASD. Only by identifying the underlying mechanisms, adequate treatment can be provided. The study by Fuentes et al. (2009) showed that in a rather small sample of children with ASD, fine motor skills significantly predicted handwriting, whereas age, gender, IQ, and visuospatial abilities did not. On the other hand, in adolescents with ASD, the same researchers found that the level of perceptual reasoning was the main predictor of handwriting. However, they did not take reading or visuo-motor abilities into account, although previous research has already established the influence of these factors. Consequently, the present study examined the predictive value of gender, age, handedness, IQ, visual-motor integration, visual perception, fine motor skills, and reading abilities in a relatively large group of children with ASD in order to identify which domains have to be examined and possibly be dealt with during handwriting remediation. In that way, a more effective therapy for each child with ASD could be applied in the future.

2. Method

2.1. Participants

In total, 131 Flemish children aged 7 to 12 participated. All had a Full Scale IQ (FSIQ) of or above 80, estimated by four subtests of the Wechsler Intelligence Scale for Children - 3rd edition (WISC-III; Wechsler, 1991): 'similarities', 'block design', 'picture arrangement', and 'vocabulary'. This abbreviated form of the WISC-III is a valid and reliable instrument to assess FSIQs (Grégoire, 2000). Seventy children were diagnosed with ASD and 61 were typically developing children. All were native Dutch speakers. Children with epilepsy or medical diagnoses interfering with their motor development (e.g., cerebral palsy) were excluded.

Children with ASD were recruited in centres of remedial education and rehabilitation or special education services. All children had previously been diagnosed with ASD by a multidisciplinary team based on the Diagnostic and Statistical Manual of Mental Disorders, 4th edition, Text Revision (DSM-IV-TR; American Psychiatric Association [APA], 2000). Thirteen of them had a comorbid diagnosis of ADHD. If applicable, these children were instructed to stop the intake of stimulant medication 24h prior to testing.

Control children were recruited in several regular schools. None of these children had a history of developmental disorders. They were screened for the presence of behaviour problems and ASD with the Disruptive Behaviour Disorder Rating Scale - Parent Version (DBDRS; Pelham, Gnagy, Greenslade, & Milich, 1992; Dutch translation: Oosterlaan, Scheres, Antrop, Roeyers, & Sergeant, 2008) and the Social Communication Questionnaire - Lifetime Form (SCQ; Rutter, Bailey, & Lord, 2003; Dutch translation: Warreyn, Raymaeckers, & Roeyers, 2004) respectively. Children were excluded if 1) one of the questionnaires was lacking or incomplete, 2) they scored outside the normal range on one of the subscales on the DBDRS, suggesting that these children possibly had behavioural problems, 3) they scored ≥ 15 on the SCQ, indicating that autistic traits were present. Furthermore, all children scored above the 15th percentile on the Movement Assessment Battery for Children - Second Edition (M-ABC-2; Henderson, Sugden, & Barnett, 2007), inferring that no motor problems were present.

There were no significant differences in age, $U = 1938$, $p = .44$, hand preference, $\chi^2(1) = .33$, $p = .57$, or gender, $\chi^2(1) = 1.51$, $p = .22$. There was a significant difference in FSIQ, $U = 2999.50$, $p \leq .001$, $r = .37$. FSIQ was not included as a covariate in the analyses since it reflects a true group difference and therefore will not reduce within-group error variation unrelated to group status (Field, 2009, pp. 397-399; Miller & Chapman, 2001).

2.2. Measures

The Dutch tool *Systematic Screening of Handwriting* (Dutch: ‘Systematische Opsporing van Schrijfmotorische Stoornissen’) (SOS; Van Waelvelde, De Mey, & Smits-

Engelsman, 2009) is a screening instrument to detect graphomotor disorders in children and is based on the Concise Assessment Method for Children's Handwriting (Dutch: 'Beknopte Beoordelingsmethode voor Kinderhandschriften') (BHK; E. Hamstra-Bletz, De Bie, & Den Binker, 1987). Participants are instructed to copy a standard text as fast and as neat as they usually do on unruled paper during five minutes or until the first five sentences have been written. These first five lines are used to determine handwriting quality by evaluating six items: 1) fluency in letter formation: i.e., abrupt changes in handwriting direction, 2) fluency in connections between letters, 3) letter height, 4) regularity in letter height, 5) spaces between words, and 6) spatial alignment of sentences. For each criterion, the manual provides several examples. With exception of item 3, a score of 0, 1, or 2 per criterion is given according to the number of deviations from the standard. A criterion is rated with a zero when abnormalities appear in no more than one line. A score of 1 is awarded when two or three lines deviate from the standard. An item is given a score of 2 when more than three lines differ markedly from the norm. Letter height is evaluated by the mean height of the first five sentences. The larger the handwriting, the higher the score (ranging from 0 to 2). For item three, four, and six, the criteria are measured using a transparent sheet provided with the manual. A total quality score is obtained by adding the six items mentioned above, ranging from 0 to 12. The higher the total score, the poorer the quality. Handwriting speed is measured by counting the number of letters written in five minutes. Scores on either handwriting quality or speed at or below the 5th percentile is an indication for a graphomotor disorder, scores between percentile 5 and 15 indicate a child at risk. The reliability and validity of the SOS was established by previous research (Van Waelvelde, Hellinckx, Peersman, & Smits-Engelsman, 2012). In our sample, the Cronbach's alpha coefficient for handwriting quality was .67.

The *Movement Assessment Battery for Children - Second Edition* is a standardized test of motor functioning and identifies movement difficulties in children (M-ABC-2; Henderson, et al., 2007; Dutch translation: Smits-Engelsman, 2010). The testing part is divided into three age categories (3-6, 7-10, 11-16), each of them consisting of eight tasks grouped under three headings: ‘manual dexterity’ (MD), ‘aiming & catching’ (A&C), and ‘balance' (BAL). Raw scores on the three components and on the total test can be converted into standard scores (*M* = 10, *SD* = 3) and percentiles. As stated in the manual, a total test score at or below the 5th percentile indicates the presence of motor difficulties. A child scoring between the 5th and 16th percentile is considered to be at risk. The M-ABC-2 is a reliable and valid tool to assess the level of motor competence in children (Henderson et al., 2007). In our sample, Cronbach’s alpha coefficient of age band 2 is .76, of age band 3 .82.

The *Developmental Test of Visual-Motor Integration* (VMI) assesses visual-motor integration skills, its supplemental test *Test of Visual Perception* (VP) visual perception (Beery et al., 2004). In the VMI, children are instructed to copy 27 geometric forms correctly. Based on criteria in the manual, each reproduced figure is scored as correct or incorrect. In the VP test, children need to identify a geometric form among other similar figures. The number of figures drawn (VMI) or identified (VP) correctly are counted and are converted into standard scores (*M* = 100, *SD* = 15). The VMI has good psychometric properties (Beery et al., 2004). The Cronbach’s alpha coefficient of the VMI, found in our sample, was .81, similar to the one reported in the manual (.82) (Beery et al., 2004).

During the *One Minute Reading Test* (Dutch: ‘Eén Minuut leesTest’ (EMT)) (OMRT; Brus & Voeten, 1999), children are instructed to read out loud as many words as possible during 1 minute. The number of words read correctly is counted and converted into a standard score (*M* = 10, *SD* = 3) according to Flemish norm tables based on 10,059 children (Ghesquière & Ruijssenaars, 1994).

2.3. Procedure

Schools, centres of remedial education and rehabilitation, and private physiotherapists were sent information letters, requesting them to distribute information about our research among parents of eligible children. Parents who agreed to participate were contacted to set up an appointment for testing and were asked to sign an informed consent. Examination took place at school, at the university lab, or at the child's centre of remedial education or rehabilitation and was conducted and scored by a physiotherapist. Each child was tested separately in a quiet room. Depending on the child's competence, testing was completed in one or two sessions. During or after these sessions, parents completed the DBDRS and the SCQ. In the latter case, prepaid envelopes were provided. The study was approved by the ethic committee of the Faculty of Psychology and Educational Sciences of our university. No financial compensation for participation was offered.

3. Results

Prior to statistical testing, outliers (= group mean ± 3 SDs) were removed. This resulted in the exclusion of one child with ASD from the analyses. In each group, Mann-Whitney tests were performed to compare handwriting quality, speed, and Standard Score (SS) MD between sexes and left- and right-handers. Mann-Whitney tests were conducted to compare age, FSIQ, handwriting quality, SS VMI, SS VP, SS OMRT, and SS MD, and an independent samples t test was conducted to compare handwriting speed between children with ASD and the control group. Pearson chi-square tests were conducted to detect possible differences in gender or hand preference between children with ASD and the TD children. Independent samples t tests were used to compare handwriting quality and speed between children with ASD with and without ADHD. Predominantly, non-parametric tests were chosen because of the skewed distribution of data.

In each group separately, Pearson or Spearman correlations were conducted to assess associations between handwriting speed, quality, and several factors (age, FSIQ, SS VMI, SS

VP, SS OMRT, SS MD). Age, FSIQ, gender, hand preference, SS VMI, SS VP, SS OMRT, and SS MD were entered into hierarchical multiple regression analyses to identify predictive factors of either quality or speed for each group separately. Assumptions of linear regression analyses (normality of standardized errors, homogeneity of variance, linearity and collinearity) were tested. The error distribution of handwriting speed in the ASD group violated the assumption of normality and homogeneity and thus bootstrap confidence intervals were computed. This reproduced an outcome similar to the multiple regression analysis. Therefore, results of the latter are presented.

In all the analyses mentioned above, raw scores of handwriting quality and speed were used. An alpha level of .05 was employed.

Children with ASD performed worse on all measures (SS VMI, SS VP, SS OMRT, SS MD, handwriting quality, and speed) compared to the control group (Table 1). Children with ASD wrote texts of lower quality because they connected letters less adequately (item 2) and wrote less fluently (item 1), larger (item 3), and with more irregularities in height (item 4) and in spatial alignment (item 6) compared to the control group ($p \leq .01$). Children with ASD with comorbid ADHD did not differ in handwriting quality, $t(67) = -1.80$, $p = .08$, or in speed, $t(67) = .39$, $p = .70$, from children with ASD without ADHD, although the former difference tended to reach significance.

[INSERT TABLE 1]

In children with ASD as well as in the control group, a series of bivariate correlation analyses yielded significant relations between handwriting quality and age (ASD: $r = -.51$, $p \leq .001$; TD: $r = -.33$, $p = .01$) and SS VMI (ASD: $r = -.27$, $p = .03$; TD: $r = -.37$, $p = .003$) (Table 2). Furthermore, in both groups, handwriting quality differed in relation to gender: boys produced handwriting of poorer quality compared to girls (girls vs. boys ($M \pm SD$): ASD: 3.45 ± 2.07 vs. 5.93 ± 2.53, $U = 143.00$, $p = .004$, $r = .35$; TD: 1.93 ± .70 vs. 3.09 ±

1.70, U = 188.00, p = .006, r = .35). Additionally, in the total sample, girls scored higher on the manual dexterity tasks of the M-ABC-2, indicating a more proficient level of fine motor skills (U = 1710.50, p = .04, r = .18). Neither in children with ASD, neither in the control group, handwriting quality between left- and right-handers differed ($p \geq .05$).

[INSERT TABLE 2]

Fifty-five per cent of the variance in handwriting quality in children with ASD (R^2 = .55; R^2 *adjusted* = .49) was explained by our regression model, $F(8,60) = 9.05$, $p \leq .001$, whereas in TD children, 46% was explained, $F(8,52) = 5.45$, $p \leq .001$. The best predictors of handwriting quality in ASD were age (standardized β = -.62, t = -6.55, $p \leq .001$), gender (standardized β = -.27, t = -2.71, p = .009), and SS VMI (standardized β = -.36, t = -3.60, p = .001). Hand preference tended to predict handwriting quality in this population (standardized β = -.17, t = -1.87, p = .07). Significant predictors of handwriting quality in TD children were age (standardized β = -.46, t = -4.08, $p \leq .001$), gender (standardized β = -.30, t = -2.76, p = .008), hand preference (standardized β = -.27, t = -2.57, p = .01), SS VMI (standardized β = -.24, t = -2.11, p = .04), and SS VP (standardized β = -.27, t = -2.19, p = .03) (Table 3 and 4).

[INSERT TABLE 3 AND 4]

In ASD as well as in the control group, handwriting speed correlated significantly with age (ASD: r = .72, $p \leq .001$; TD: r = .75, $p \leq .001$) and SS OMRT (ASD: r = .53, $p \leq .001$; TD: r = .37, p = .003). In TD children, handwriting speed tended to correlate with FSIQ (r = .21, p = .10) and SS VMI (r = .23, p = .08) (Table 2). In both groups, right- and left-handers wrote a very similar number of letters in five minutes. Moreover, there was no significant difference between boys and girls ($p \geq .05$). In children with ASD, no less than 75% of the variance in handwriting speed (R^2 *adjusted* = .71) was explained by our regression model, $F(8,60) = 22.25$, $p \leq .001$ (Table 5). The best predictors were age (standardized β = .65, t = 10.82, $p \leq .001$), gender (standardized β = .16, t = 2.36, p = .02), SS OMRT (standardized β =

.44, t = 6.76, $p \leq .001$), and SS MD (standardized β = .16, t = 2.34, p = .02). The causal relation between speed and FSIQ tended to reach significance (standardized β = .10, t = 1.72, p = .09). In the control group, 68% of the variance was explained (R^2 *adjusted* = .63), $F(8,52)$ = 13.85, $p \leq .001$ (Table 6). The best predictors were age (standardized β = .75, t = 8.63, $p \leq$ .001), gender (standardized β = .17, t = 2.07, p = .04), and SS OMRT (standardized β = .18, t = 1.97, p = .05).

[INSERT TABLE 5 AND 6]

4. Discussion

The present study was designed to determine to what extent demographic, perceptual, motor, and cognitive variables predict handwriting quality and writing speed in children with ASD. Below, the influence of each factor is delineated and discussed.

In the present study, children with ASD wrote fewer letters in five minutes, which is in contrast with the findings of Fuentes et al. (2009, 2010). These researchers observed no lower rate in children or adolescents with ASD, but ascribed this to their writing task, which possibly lacked sensitivity to detect possible differences. In addition, in our study, children with ASD wrote texts of poorer quality than the control group. More specifically, they did not connect letters correctly, wrote larger, and with more irregularities in height and in spatial arrangement. In adults as well as in adolescents with ASD, similar features have been observed (Beversdorf et al., 2001; Fuentes et al., 2010), whereas in children, no differences in alignment, sizing, or spacing compared to TD children have been reported (Fuentes et al., 2009). In the last study, participants had to copy on baselines and had to match a handwriting example, which is in contrast with our study. Different instructions in various examinations thus possibly explain discrepancies between our study and the one of Fuentes et al. (2009).

The present study confirms the outstanding performance of girls regarding handwriting quality observed in previous research: girls with ASD produced a text of better quality than boys (Berninger & Fuller, 1992; Graham et al., 1998; Ziviani & Elkins, 1984). This gender difference was also present in the control group. Hartley (1991) suggested that the difference in quality can possibly be explained by the fact that girls benefit from more proficient fine motor skills. Indeed, in our total sample, girls obtained higher scores on the subtest ‘manual dexterity’ of the M-ABC-2, supporting this assumption. Regarding writing speed, both girls and boys with ASD produced an equal amount of written work. A similar finding was observed in TD children. Since no consensus on writing rate has been reached amongst researchers, this finding both differs from as well as strokes with previous research (Berninger & Fuller, 1992; Graham et al., 1998; Rueckriegel et al., 2008; Ziviani & Elkins, 1984; Ziviani & Watson-Will, 1998). The equality between boys and girls with respect to text volume in our study seems plausible because of the age range of our sample (7 till 12 years). Speed differences between sexes at certain moments during development, namely the higher rate of girls aged 7-10 and of boys aged 11-12, were probably balanced out and finally resulted in a similar writing speed (Ziviani & Watson-Will, 1998). However, in children with ASD in specific, Fuentes et al. (2009) found no influence of gender on handwriting performances. Differences in tasks, as mentioned above, may explain the discrepancy between our study and theirs. Furthermore, since they tested merely 3 girls with ASD, their analysis possibly lacked power to detect any dissimilarities. Finally, in their study, speed and quality were collapsed into one handwriting variable, which might have cancelled effects of gender on either speed or quality separately.

In accordance with the overall view that handwriting performances do not differ between left- and right-handers, in the present study, left-handed children neither produced written texts of inferior quality, nor wrote more letters than right-handers, which was the case in the ASD as well as in the control group. Hand preference predicted and tended to predict handwriting quality in the TD control and the ASD group respectively, meaning that when all the other variables in the model would remain constant, left-handed children would write, or tend to write, with a poorer quality than right-handed children. However, other variables also influenced writing quality, possibly cancelling the effect of handedness when comparing the performance of left- and right-handers in both groups.

In the present study, age had the highest influence on both handwriting quality and speed in children with ASD as well as in the control group. As expected, we found that quality and speed enhanced during development (Graham et al., 1998; Rueckriegel et al., 2008; Ziviani & Elkins, 1984), possibly due to maturation of essential writing components and/or the increasing volume of formal handwriting instructions and/or practice (Beery et al., 2004; Marr, Cermak, Cohn, & Henderson, 2003; Marr & Dimeo, 2006). However, Fuentes et al. (2009, 2010) did not find any influence of age in children or adolescents with ASD, which is in contrast with our result. As mentioned above, several differences (various tasks, different sample sizes, speed and quality collapsed into one variable) between studies may underlie this discrepancy.

In children with ASD, better coordination between visual input and finger movements resulted in written output of higher quality. Additionally, a more advanced degree of manual dexterity as well as better technical reading skills resulted in an increased number of letters produced in five minutes. Also in the study of Fuentes et al. (2009), motor skills significantly predicted handwriting performances in children with ASD. Previous research findings in a variety of populations regarding the influence of visual-motor integration, fine motor skills, and reading abilities (Barnhardt et al., 2005; Biemiller et al., 1993, as cited in Graham & Weintraub, 1996, p. 34; Bumin & Kavak, 2008; Daly et al., 2003; L. Hamstra-Bletz & Blöte, 1993; Kandel et al., 2006; Kulp, 1999; Maeland, 1992; Overvelde & Hulstijn, 2011; Preminger et al., 2004; Tseng & Chow, 2000; Volman et al., 2006) are also in line with our findings. On the other hand, the level of visual perception did not correlate with or predicted handwriting speed or quality. This is in accordance with other studies both in children with ASD (Fuentes et al., 2009) and in other populations (Volman et al., 2006; Tseng & Chow, 2000; Yost, 1980). However, the present study focused merely on one domain of visual perception, leaving the possibility that other areas perhaps do influence handwriting performances in ASD. Indeed, Tseng and Chow (2000) found that visual discrimination did not predict writing rate in slow writers, whereas visual sequential memory did. Finally, the causal relation between FSIQ and speed tended to reach significance, which is in contrast with the study of Fuentes et al. (2009). On the other hand, in adolescents with ASD, the perceptual reasoning index of the Wechsler Abbreviated Scale of Intelligence or Wechsler Intelligence Scale for Children was the main predictor of handwriting performances (Fuentes et al. 2010). Besides, other studies also found correlations between IQ and handwriting speed (Berninger et al., 1992; McKay & Neale, 1985).

Interestingly, in the control group, not only did the level of visual-motor integration significantly predict handwriting quality, but also the level of visual perception was of influence. Besides, neither manual dexterity nor FSIQ had an impact on the number of letters written by TD children. These results suggest that different mechanisms underlie handwriting performances in TD children compared to children with ASD, implying that therapy for handwriting difficulties should address other processes in these two groups.

Overall, our findings indicate that, in children with ASD, writing is a complex interaction of perceptive, motor, and cognitive processes. A striking result is the high influence of reading skills on handwriting speed. Children who read more words correctly out loud in one minute wrote more letters in five minutes, which seems logical. Children with reading problems possibly spent less time writing but more time identifying which words they needed to write compared to those with good technical reading skills. Although various studies have revealed common processes in reading and writing, in addition, they have also stressed the uniqueness of these literacy skills (Fitzgerald & Shanahan, 2000). Therefore, improvement over time in either reading or writing, due to development or extra instructions, can lead to enhancement in both skills, but specific instructional attention should not be neglected (Graham & Hebert, 2010). In addition to our findings, it would also be interesting to know whether the links between writing and reading skills are limited to timed reading tasks or whether, for example, comprehensive reading tasks are also related to writing speed. Importantly, despite the well-known link between reading and writing, the degree of reading skills is often overlooked during treatment of writing difficulties in general (Feder & Majnemer, 2007). Rather than focussing solely on visual-motor processes or motor control, handwriting remediation should address reading skills as well.

This research project aimed to reveal which factors predict handwriting quality and speed in children with ASD. Whether these variables also influence handwriting processes has not been examined. Since handwriting is a dynamic task, future handwriting evaluations addressing this topic should also incorporate digitizer-based assessments in addition to judgements of the handwriting product in order to understand the full impact of these variables (Rosenblum, Weiss, & Parush, 2003).

In our study, a substantial part of variance in either handwriting quality or speed in ASD was not explained, indicating that other predictive factors must exist. Another factor of interest according to other researchers is the ability to sustain attention. A child must be capable to concentrate during a longer time span in order to complete a writing task adequately (Feder & Majnemer, 2007). Indeed, several studies have reported poorer handwriting performances in children with ADHD (Adi-Japha et al., 2007; Brossard-Racine, Majnemer, Shevell, & Snider, 2008; Brossard-Racine, et al., 2011). Since many children with ASD have co-morbid attention problems (Simonoff et al., 2008), this might indeed explain handwriting problems in children with ASD. In our study, the difference in handwriting quality in children with ASD combined with ADHD and children with only ASD tended to reach significance, indicating that attention disorders in ASD might indeed influence handwriting performances. Besides attention deficits, proprioception and tactile information have also been identified as influencing variables. In a study of Hepp-Reymond, Chakarov, Schulte-Monting, Huethe, and Kristeva (2009), a deafferented patient, completely insensitive to cutaneous and proprioceptive input, wrote dysfluent and non-automatically with imprecise letter shapes, although vision was present. Additionally, Teasdale et al. (1993) found that proprioceptive information is indispensable to calibrate the hand in space during writing. Ebied, Kemp, and Frostick (2004) stressed the importance of tactile input by demonstrating that blocking tactile sensation resulted in a diminution of writing smoothness and directness in healthy adults. Future research should thus include measurements assessing proprioceptive and tactile processing to establish whether or not, in children with ASD, these factors play an important role in handwriting.

Furthermore, future studies should include different ethnicities in order to get a better insight into handwriting abilities of Flemish children with ASD since a significant part of this population is of foreign origin. In addition, replicating our study in more countries would also be of interest since it would reveal whether the same variables would predict handwriting performances in other languages as well.

4.1. Conclusion

Handwriting is a complex task in which diverse processes interact. In children with ASD, age, gender, and visual-motor integration skills influence handwriting quality, whereas age, reading abilities, and manual dexterity influence writing speed. These predictors slightly differ from the ones in TD children indicating that different mechanisms may underlie handwriting in both groups. An important practical implication of these findings is that, instead of solely addressing visual-motor processes or motor coordination, handwriting remediation in children with ASD should tackle reading skills as well.

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Table 1. *Group means on demographic, cognitive, perceptual, and motor factors*

	Group				
	ASD (n = 69)		TD (n = 61)		
Measure	*M*	*SD*	*M*	*SD*	
Age	10.49	(1.49)	10.33	(1.23)	U = 1938
FSIQ	98.14	(13.29)	108.05	(13.12)	U = 2999.50***
SS VMI	86.32	(11.19)	100.41	(13.12)	U = 3407.50***
SS VP	98.12	(11.78)	106.67	(13.02)	U = 2794.50***
SS OMRT	6.48	(3.83)	9.36	(2.97)	U = 2972***
SS MD	5.97	(3.64)	10.33	(3.16)	U = 3457***
HW quality	5.54	(2.61)	2.80	(1.59)	U = 832.50***
Fluency	.94	(.80)	.28	(.56)	U = 1142.50***
Connections	.61	(.77)	.26	(.55)	U = 1605**
Letter height	.71	(.60)	.21	(.45)	U = 1168.50***
Regularity in height	1.04	(.76)	.54	(.59)	U = 1329***
Spaces	1.14	(.68)	1.36	(.78)	U = 1986.50
Spatial alignment	.74	(.72)	.16	(.42)	U = 1165.50***
HW speed	191.14	(72.70)	242.75	(67.18)	$t(128) = -4.19$***

Note. ASD = Autism Spectrum Disorder. TD = Typically Developing control group. FSIQ = Full Scale Intelligence Coefficient. VMI = Visual-Motor Integration. VP = Visual Perception. OMRT = One Minute Reading Test. MD = Manual Dexterity. SS = Standard Score. HW = Handwriting.
** $p \leq .01$. *** $p \leq .001$

Table 2.1 *Intercorrelations between handwriting measures and demographic, cognitive, perceptual, or motor variables in children with ASD*

Measure	1	2	3	4	5	6	7	8
1. Quality	--	-.52***	.15	-.51***	-.27*	-.04	-.06	-.08
2. Speed		--	.19	.72***	-.06	-.06	.53***	.08
3. FSIQ			--	-.03	.17	.30**	.28*	.26*
4. Age				--	.27*	.25*	.20	-.09
5. SS VMI					--	.35**	.07	.38***
6. SS VP						--	.12	.24*
7. SS OMRT							--	-.14
8. SS MD								--

Note. ASD = Autism Spectrum Disorder. FSIQ = Full Scale Intelligence Coefficient. VMI = Visual-Motor Integration. VP = Visual Perception. OMRT = One Minute Reading Test. MD = Manual Dexterity. SS = Standard Score.
$*p \leq .05$. $**p \leq .01$. $***p \leq .001$.

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Table 2.2 *Intercorrelations between handwriting measures and demographic, cognitive, perceptual, or motor variables in TD control children*

Measure	1	2	3	4	5	6	7	8
1. Quality	--	-.38	.03	-.33**	-.37**	-.07	-.10	-.09
2. Speed		--	.21	.75***	.23	-.13	.37**	.12
3. FSIQ			--	.20	.29*	.38**	.39**	.24
4. Age				--	.29*	-.18	.17	-.04
5. SS VMI					--	.16	.19	.23
6. SS VP						--	.23	.28*
7. SS OMRT							--	.16
8. SS MD								--

Note. TD = Typically Developing. FSIQ = Full Scale Intelligence Coefficient. VMI = Visual-Motor Integration. VP = Visual Perception. OMRT = One Minute Reading Test. MD = Manual Dexterity. SS = Standard Score.
$*p \leq .05$. $**p \leq .01$. $***p \leq .001$.

Table 3. *Intercorrelations between handwriting measures and demographic, cognitive, perceptual, or motor variables in TD control children*

Measure	1	2	3	4	5	6	7	8
1. Quality	--	-.38	.03	-.33**	-.37**	-.07	-.10	-.09
2. Speed		--	.21	.75***	.23	-.13	.37**	.12
3. FSIQ			--	.20	.29*	.38**	.39**	.24
4. Age				--	.29*	-.18	.17	-.04
5. SS VMI					--	.16	.19	.23
6. SS VP						--	.23	.28*
7. SS OMRT							--	.16
8. SS MD								--

Note. TD = Typically Developing. FSIQ = Full Scale Intelligence Coefficient. VMI = Visual-Motor Integration. VP = Visual Perception. OMRT = One Minute Reading Test. MD = Manual Dexterity. SS = Standard Score.
$^*p \leq .05$. $^{**}p \leq .01$. $^{***}p \leq .001$.

Table 4. *Predictors of handwriting quality in TD children*

	Handwriting quality				
Variable	*B*	*SE B*	*β*	*t*	95% CI
Constant	17.40	2.69		6.46***	[12.00, 22.81]
Age	-.59	.15	-.46	-4.08***	[-.88, -.30]
Gender	-1.11	.40	-.30	-2.76**	[-1.92, -.31]
Hand preference	-1.44	.56	-.27	-2.57**	[-2.56, -.32]
FSIQ	.01	.02	.09	.66	[-.02, .04]
SS VMI	-.03	.02	-.24	-2.11*	[-.06, -.002]
SS VP	-.03	.02	-.27	-2.19*	[-.06, -.003]
SS OMRT	.07	.06	.12	1.05	[-.06, .19]
SS MD	.05	.06	.10	.89	[-.06, .16]
R^2	.46				
$F(8,52)$	5.45***				

Note. TD = Typically Developing control group. FSIQ = Full Scale Intelligence Coefficient. SS = Standard Score. VMI = Visual-Motor Integration. VP = Visual Perception. OMRT = One Minute Reading Test. MD = Manual Dexterity. CI = Confidence Interval.
*$p \leq .05$. **$p \leq .01$. ***$p \leq .001$.

Table 5. *Predictors of handwriting speed in children with ASD*

	Handwriting speed				
Variable	*B*	*SE B*	*Β*	*t*	95% CI
Constant	-287.73	65.74		-4.37***	[-495.25, -178.89]
Age	31.77	2.94	.65	10.82***	[24.92, 38.62]
Gender	30.81	13.08	.16	2.36*	[1.99, 59.62]
Hand preference	19.03	16.22	.09	1.17	[-10.13, 48.18]
FSIQ	.55	.32	.10	1.72	[-.25, 1.36]
SS VMI	.05	.39	.01	.12	[-.93, 1.03]
SS VP	-.08	.46	-.01	-.17	[-.96, .80]
SS OMRT	8.31	1.23	.44	6.76***	[5.51, 11.11]
SS MD	3.26	1.39	.16	2.34*	[.33, 6.20]
R^2	.75				
$F(8,60)$	22.25***				

Note. ASD = Autism Spectrum Disorder. FSIQ = Full Scale Intelligence Coefficient. SS = Standard Score. VMI = Visual-Motor Integration. VP = Visual Perception. OMRT = One Minute Reading Test. MD = Manual Dexterity. CI = Confidence Interval.
**$p \le .01$. ***$p \le .001$.

Table 6. *Predictors of handwriting speed in TD children*

	Handwriting speed				
Variable	*B*	*SE B*	*β*	*t*	95% CI
Constant	-301.41	87.21		-3.46***	[-476.42, -126.41]
Age	40.59	4.70	.75	8.63***	[31.15, 50.03]
Gender	26.89	13.02	.17	2.07*	[.76, 53.02]
Hand preference	23.98	18.13	.11	1.32	[-12.40, 60.36]
FSIQ	.07	.51	.01	.13	[-.97, 1.10]
SS VMI	-.22	.48	-.04	-.45	[-1.18, .75]
SS VP	.01	.48	.001	.01	[-.96, .97]
SS OMRT	3.98	2.02	.18	1.97*	[-.07, 8.03]
SS MD	2.21	1.82	.10	1.22	[-1.44, 5.86]
R^2	.68				
F	13.85***				

Note. TD = Typically Developing control group. FSIQ = Full Scale Intelligence Coefficient. SS = Standard Score. VMI = Visual-Motor Integration. VP = Visual Perception. OMRT = One Minute Reading Test. MD = Manual Dexterity. CI = Confidence Interval.
$^*p \leq .05$. $^{***}p \leq .001$.