Characteristics of handwriting quality and speed in adults with autism spectrum disorders

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Abstract & Keywords

Abstract

Background: Handwriting difficulties affecting production quality and speed have been identified in children and adolescents with autism spectrum disorders (ASD), and several perceptual-motor impairments have been shown to contribute to these difficulties. There has been only one study of handwriting in adults with ASD, and this focused on letter size, reporting macrographia. The present study was therefore intended to explore the other features of handwriting and the role of perceptual-motor skills in this activity in adults with ASD.

Method: We recruited a group of adults with ASD (n = 21) and two typically developing control groups, matched on either chronological (n = 21) or developmental (n = 21) age. Participants performed a handwriting copy task to assess handwriting speed and quality, and five perceptual-motor tasks (finger dexterity, fine motor coordination, graphomotor activity, visuomotor integration, and visual attention).

Results: Adults with ASD had significantly poorer handwriting quality than adults in the two control groups, and lower handwriting speed than adults of the same chronological age. Developmental age was the best predictor of handwriting quality in adults with ASD, whereas visuomotor integration was the best predictor in the control group matched on developmental age. None of the factors we tested influenced production speed in adults with ASD.

Conclusions: Handwriting in adults with ASD appears to show weaknesses and peculiarities. Further studies are needed to explore alternative predictive factors for handwriting speed and quality in adults with ASD, in order to improve handwriting and consequently increase employment opportunities for this population.

Keywords:

Handwriting quality, handwriting speed, ASD, adults, predictors

1. Introduction

Studies of handwriting in autism spectrum disorders (ASD) have mainly been conducted in children and adolescents, and have generally reported reduced quality and speed of production (see Kushki et al., 2011, for a review).

Handwriting is a complex activity that requires both high-level (linguistic, semantic, syntactic and orthographic) and low-level (motor, perceptual and kinesthetic) processes (for a review, see Bara & Gentaz, 2010). In the present study, we were interested in low-level processes, and more particularly in the way that hand movements are produced to form letters.

Handwriting can be assessed using either product or process analysis. To analyze the handwriting *product* in ASD, most studies use standardized tests addressing two aspects of handwriting, namely quality and speed (Fuentes et al., 2009, 2010; Hellinckx et al., 2013; Henderson & Green, 2001; Myles et al., 2003; Rosenblum et al., 2015). In these tests, participants generally have to copy visually presented words, sentences or text on a white sheet of paper (with or without lines, according to the test), in their usual handwriting. Depending on the test, various criteria for letter formation or spatial organization are used to establish an overall handwriting quality score (Rosenblum et al., 2003). Some quality scores are established on the basis of letter size, shape, or consistency, while others are calculated from the number of recognizable letters and the number of errors. Production speed is measured as the number of characters or words produced within a given period of time.

To our knowledge, only 11 studies have focused on the handwriting product in ASD (Frith, 1991; Beversdorf et al., 2001; Cartmill, Rodger, & Ziviani, 2009; Fuentes et al., 2009, 2010; Hellinckx et al., 2013; Henderson & Green, 2001; Johnson, Phillips, et al., 2013; Kushki, Chau, & Anagnostou, 2011; Myles et al., 2003; Rosenblum et al., 2015). These showed that, compared with their typically developing (TD) peers, children and adolescents with ASD have several difficulties, reflected in a lower overall quality score (Fuentes et al., 2009, 2010; Hellinckx et al., 2013; Myles et al., 2003; Rosenblum et al., 2015).

Some authors have found that children with ASD produce large handwriting, or *macrographia* (Hellinckx et al., 2013; Johnson, Phillips et al., 2013; Myles et al., 2003). However, there is no consensus over this result, as other studies have shown that the size of their handwriting is comparable to that of TD children (Fuentes et al., 2009, 2010; Johnson, Papadopoulos et al., 2013).

These contradictory results may be explained by methodological discrepancies (sample size, assessment criteria, etc.). For example, whereas Hellinckx and colleagues (2013) evaluated handwriting size by asking participants to copy out a text on a blank sheet of paper, Fuentes and colleagues (2009) evaluated it by asking participants to copy out words on solid lines. Writing on lines influences movement trajectory and handwriting size (Johnson et al., 2015).

The majority of studies have reported difficulty with letter formation among children and adolescents with ASD (Cartmill et al., 2009; Fuentes et al., 2009; Hellinckx et al., 2013; Henderson & Green, 2001; Johnson, Phillips et al., 2013; Myles et al., 2003). The handwriting of children with ASD is characterized by poor spatial arrangement of the letters, compared with that of their TD peers (Hellinckx et al., 2013; Myles et al., 2003; Rosenblum et al., 2015). Children and adolescents with ASD make fewer spaces between letters and words, compared with control groups matched on age and IQ (Fuentes et al., 2010; Johnson, Papadopoulos et al., 2013; Rosenblum et al., 2015). Regarding handwriting speed, some studies have shown that they write more slowly than their peers (Hellinckx et al., 2013; Henderson & Green, 2001), although Cartmill and colleagues (2009) failed to find any significant difference between children with ASD and TD controls matched for age, IQ and academic level.

All these studies looked at children and adolescents, and there has so far been only one study of handwriting in adults with ASD, who were compared with adults matched on chronological age (CA) and level of general cognitive functioning (Beversdorf et al., 2001). Focusing on letter height, these authors found that the handwriting of participants with ASD was characterized by larger letters than that of controls, as observed in children and adolescents with ASD (Johnson, Phillips, et al., 2013; Myles et al., 2003). This macrographia may reflect a compensatory strategy designed to maximize tactile-kinesthetic sensations and thus make it easier to control the trajectory of handwriting movements–a strategy adopted by TD children in the course of learning (Chartrel & Vinter, 2006; Zesiger et al., 2000).

Many factors contribute to the development of handwriting in TD children (Kaiser, 2009) and children with ASD (Hellinckx et al., 2013; Kushki et al., 2011). A deficit in one or more of these factors can affect both the quality and speed of handwriting. Age has been found to be a predictor of the development of handwriting quality and speed in both TD children (Sage, 2010) and children with ASD

(Hellinckx et al., 2013). General motor skills and fine motor skills have also been identified as predictive factors of handwriting quality in children with ASD (Fuentes et al., 2009; Hellinckx et al., 2013). Strong correlations have been found between motor skill scores on stressed gait tasks (heel walking, toe walking, walking on the sides of the feet, and tandem walking) and balance tasks (standing and hopping on one foot), time taken to execute movements, and overall handwriting quality score in children with ASD (Fuentes et al., 2009). Visuomotor integration also contributes to handwriting performances in ASD (Hellinckx et al., 2013; Mayes & Calhoun, 2007). Children with ASD score significantly lower on visuomotor integration (copying geometric forms) and visual perception (identifying a geometric form among other similar figures) than their TD peers (Hellinckx et al. 2013), but visuomotor integration is a predictive factor for handwriting quality in both groups. In adolescents with ASD, perceptual reasoning has also been found to predict handwriting quality, indicating changes in the underlying mechanisms (Fuentes et al., 2010). Regarding handwriting speed, one study reported that during a copy task, children with ASD who also had reading problems spent more time reading the words and less time writing, indicating that reading skills are a predictive factor for handwriting speed in ASD (Hellinckx et al. ,2013).

As indicated above, there has so far been only one study of the handwriting product in adults with ASD, which reported macrographia (Beversdorf et al., 2011).

It was this lack of information on handwriting in adults with ASD that led us to conduct the present two-part study, designed to 1) characterize the handwriting of adults with ASD in terms of quality and speed of production, and 2) identify the predictive factors for handwriting quality and speed in the adult participants.

Given the limited information available on handwriting in adults with ASD, it is important to ascertain whether and to what extent the handwriting difficulties observed in children and adolescents persist in adults and hamper them in their daily and professional lives, in order to implement the most appropriate interventions. To achieve this better understanding, we need to identify the predictors of handwriting. Given our clinical experience with adults across the whole autism spectrum, we predicted that some of them at least, particularly those with associated verbal or intellectual disabilities, would have poorer handwriting quality and speed than adults of the same CA and developmental age (DA). We also investigated whether clinical and perceptual-motor features (i.e., age, sex, handedness, visuomotor integration, visual attention, finger dexterity, graphomotor skills and fine motor coordination) influence handwriting quality and speed.

2. Method

Participants

In total, data were collected from 63 individuals divided into three groups. The first group included 21 adults (eight women and thirteen men) with ASD, aged 18–35 years (*M* = 26.3, *SD* = 4.6). Of these, 16 were right-handed and five were left-handed. These adults were recruited via a French homecare service for adults with ASD. All had previously been diagnosed by a specialist multidisciplinary team for adults with ASD, on the basis of DSM-5 (American Psychiatric Association, 2013) criteria for ASD. All the adults with ASD had a full-scale IQ greater than 75, as measured by the Wechsler Adult Intelligence Scale IV (Wechsler, 2008). None of the adults with ASD had any comorbid diagnoses (developmental coordination disorder/dyspraxia), and none were reported to have been taking any type of medication.

We administered Raven's Standard Matrices test (Raven, 1998) probing visuospatial reasoning, together with a set of nonverbal intelligence tests eliciting analogical and inductive-logical reasoning, to all the adults with ASD to establish their DA.

In order to compare the handwriting characteristics of adults with ASD and those of TD individuals, 21 adults matched on CA, sex and handedness, and 21 children matched on DA, sex and handedness, also took part in the study. They were recruited from various primary and secondary schools in Aix-en-Provence and Marseille, and from the researchers' network of contacts. These control participants were assumed to be TD if there was no available record of neurological or developmental disorders. Participants' main characteristics are shown in Table 1.

(Table 1 about here)

Procedure

The study was approved by the ethics committee of Aix-Marseille University (no. 2015-07-01-007), and was carried out in accordance with the Declaration of Helsinki as revised in 2000. Before starting the assessment, all the participants received an information leaflet setting out the purpose of the study and describing its procedure, and gave their written informed consent. The study was performed at the

UserLab research platform (Aix-Marseille University). Participants were tested individually in a quiet room for a maximum of 45 minutes.

3. Study 1

Materials & Design

We administered the French adaptation (Charles, Soppelsa, & Albaret, 2004) of the Concise Evaluation Scale for Children's Handwriting (BHK; Hamstra-Bletz & Blöte, 1993) to assess the handwriting quality and speed of all the participants. This scale consists in copying out a text for five minutes or until the participant finishes writing the first five sentences. The text is placed on the table, next to a white sheet of paper. The first five sentences are in a larger font size than the rest of the text. Participants are told to write as they usually do, with the same quality and at the same speed. The handwriting assessment is based on the first five sentences, which are made up entirely of monosyllabic words. An overall score of handwriting quality is calculated on the basis of 13 criteria reflecting pathological morphokinetic and topokinetic aspects: large letter size, left margin widening, poor word alignment, insufficient word spacing, chaotic writing, irregularities in joining strokes, collision of letters, inconsistent letter size, incorrect relative height of letters, letter distortion, ambiguous letter forms, correction of letter forms, and unsteady writing. For each of the five sentences, a score of 1 is allocated for every criterion that is met by the handwriting. Each unmet criterion is scored 0. Two experimenters blindly scored participants' productions. Interrater reliability was $r = 0.84$.

The maximum possible total score is therefore 65. The lower the score, the better the handwriting quality. Handwriting speed is measured as the number of characters (letters and punctuation signs) written during the five minutes. The participants' handedness was also scored by the experimenter.

Data analysis

To test the effect of group on the overall BHK scores of quality and speed, we ran statistical analyses of variance (ANOVAs) between the three groups (ASD, CA, DA). Tukey's post hoc HSD test was used to analyze significant main effects through pairwise comparisons. To understand the nature of the differences, we ran analyses on each of the 13 BHK criteria. As the scores for these criteria did not follow the normal distribution (Kolmogorov-Smirnov test for normality), we used the nonparametric

Kruskal-Wallis statistical test to compare the three groups, and the Mann-Whitney *U* test to conduct pairwise group comparisons.

The alpha significance level was set at 0.05. Effect sizes, measured by partial eta squared (η^2_p), that were equal to or greater than 0.01, 0.06 or 0.14 were defined respectively as small, medium or large (Lakens, 2013). Statistica 7.1 software was used to perform these analyses.

Results

Comparisons of handwriting quality across groups

To compare the handwriting performances of the three groups of participants, we analyzed the overall BHK quality score, bearing in mind that the lower the score, the better the handwriting. ANOVAs revealed a main effect of group on the overall score, $F(2, 60) = 15.00$, $p < .001$, $\eta^2_p = .33$. A post hoc test indicated that the ASD group's performance was significantly poorer than that of both the CA ($p < .001$) and DA ($p < .001$) groups (Table 2). There was no significant difference between the CA and DA groups ($p = .15$). To identify the criteria that explained these differences, we ran Kruskal-Wallis analyses for the 13 criteria, which highlighted significant effects of group on poor word alignment ($\chi^2 = 16.34$, $p < .001$) and ambiguous letter forms ($\chi^2 = 6.75$, $p < .05$), and marginal effects on left margin widening ($\chi^2 = 5.59$, $p = .06$), insufficient word spacing ($\chi^2 = 5.87$, $p = .053$), and inconsistent letter size ($\chi^2 = 5.64$, $p = .06$). We subjected the 13 subscores to the Mann-Whitney *U* test (Table 2).

(Table 2 about here)

The ASD group scored higher (i.e. performed more poorly) than the CA group on the following criteria: left margin widening ($U = 168$, $p < .05$), poor word alignment ($U = 74.5$, $p < .001$), chaotic writing ($U = 152$, $p < .05$), and inconsistent letter size ($U = 141$, $p < .05$). Comparisons between the ASD and DA groups revealed that the former had higher mean scores for poor word alignment ($U = 100$, $p < .01$), letter distortion ($U = 178.5$, $p < .05$), and ambiguous letter forms ($U = 122.5$, $p < .01$). An illustration of the productions for each group was inserted in Figure 1.

(Figure 1 about here)

Comparisons of handwriting speed across groups

We calculated a production speed score for each participant. The groups' mean scores and their standard deviations are provided in Table 3. An ANOVA revealed a main effect of group on production speed, $F(2, 60) = 5.56$, $p < .01$, $\eta^2_p = .16$, and a post hoc test indicated that production speed was lower for the ASD group than for the CA group ($p < .01$). There was no significant difference between the ASD and DA groups ($p = .71$)

(Table 3 about here)

4. Study 2

Materials & Design

We also assessed participants' perceptual-motor skills with five subtests of the Developmental Neuropsychological Assessment (NEPSY I; Korkman et al., 2003): finger dexterity, fine motor coordination, graphomotor skills, visuomotor integration, and visual attention. *Finger dexterity* was assessed with a finger-tapping task (simple repetitive or sequential movements). *Fine motor coordination* was estimated as the ability to imitate hand or finger positions from a model. A geometric figure copy task was used to measure *graphomotor skills*. The *visuomotor integration* subtest measured the speed of fine motor movements and the accuracy of hand-eye coordination. Participants had to draw a line inside a path as quickly as possible, without leaving the track. For this subtest, there were three scores: overall score, time to execute the task, and number of errors. The type of pen grasp (immature, intermediate or mature) used during the assessment was scored. The *visual attention* subtest was used to assess the speed and accuracy of attention maintenance: participants had to find visual stimuli among distractor pictures. This subtest also had three scores: overall score, time taken to complete the exercise, and number of correct answers.

Data analysis

We ran simple linear regressions for each group to measure associations between handwriting and CA, DA, finger dexterity, fine motor coordination, graphomotor skills, visuomotor integration (overall score, time and number of errors), and visual attention (overall score, time and number of correct answers). CA and DA, sex, handedness, pen grasp and perceptual-motor skills were entered into hierarchical stepwise multiple regression analyses to identify the predictive factors for handwriting quality or speed in each group.

Results

Predictors of quality and speed of production in the ASD group

The results of correlation analyses in the ASD group are set out in Table 4. Among the adults with ASD, the simple linear regression analysis indicated that handwriting quality was significantly influenced by handwriting speed (β = -.44, t = -2.11, p < .05), as well as by DA (β = -.74, t = -4.83, p < .001), finger dexterity (β = -.50, t = -2.48, p < .05), graphomotor skills (β = -.59, t = -3.17, p < .01), and visuomotor integration (β = -.57, t = -3.04, p < .01). The multiple hierarchical regression revealed that DA (β = -0.59, t = -2.59, p < .05) was the best predictor of handwriting quality, explaining 55% of the variance in handwriting quality in the adults with ASD (R^2 = 0.55, R^2 adjusted = .53, p < .001).

(Table 4 about here)

We also analyzed speed of production. The linear regression analysis failed to reveal any significant correlations between handwriting speed and the factors we assessed (all *p*s > .05). Furthermore, when we ran the multiple regression to identify the most predictive factors for handwriting speed, we found that none of the factors we studied explained the variance in handwriting speed, F(5, 15) = 1.31, p = .41.

Predictors of handwriting quality and speed in the CA group

The results of correlation analyses in the CA group are set out in Table 5. In the CA group, the linear regression analysis showed that perceptual-motor factors had no significant influence on handwriting quality. Similarly, the multiple regression failed to identify any factors that explained the scores for handwriting quality, F(7, 13) = 1,32, p = .37.

(Table 5 about here)

Regarding speed of production, the linear regression analysis revealed a significant influence of CA (β = .60, t = 3.29, p < .01), fine motor coordination (β = 0.55, t = 2.85, p < .01), overall visual attention (β = .75, t = 5.01, p < .001), and visual attention time (β = -.64, t = -.61, p < .01) on production speed. The most explanatory model of handwriting speed was the one grouping CA (β = .32, t = 2.61, p < .05), sex (β = .39, t = 3.25, p < .01), visuomotor integration errors (β = .31, t = 2.59, p < .05) and overall visual attention (β = .41, t = 3.27, p < .01), which explained 86% (R^2 = .86, R^2 adjusted = .81, p < .001) of the variance in handwriting speed in this group.

Predictors of handwriting quality and speed in the DA group

The results of correlation analyses in the DA group are set out in Table 6. In the DA group, the linear regression analysis revealed a significant influence of handwriting speed (β = -.52, t = -2.67, p < .05), visuomotor integration errors (β = .54, t = 2.80, p < .05) and visual attention time (β = .47, t = 2.30, p < .05) on handwriting quality. The influence of CA (β = -.42, t = -2.05, p = .055), visuomotor integration time (β = 43, t = -2.05, p = .054), and overall visuomotor integration (β = -.42, t = -2.03, p = .057) on handwriting quality tended toward significance. The best predictors of handwriting quality in the DA group were visuomotor integration time (β = -.54, t = 3.44, p < .01) and errors (β = .64, t = 4.06, p < .001), which explained 57% of the variance (R^2 = .57, R^2 adjusted = .53, p < .001).

(Table 6 about here)

Handwriting speed in the DA group was significantly influenced by CA (β = .48, t = 2.40, p < .05), visuomotor integration time (β = -.55, t = -2.86, p < .01), and visual attention time (β = -.61, t = -3.38, p < .01). The best model for explaining handwriting speed in the DA group included graphomotor skills (β = .39, t = -2.20, p < .05), visual attention time (β = -.91, t = -5.00, p < .001), and pen grasp (β = .47, t = 2.99, p < .01), which explained 62% (R^2 = .62, R^2 adjusted = .56, p < .001) of the variance.

5. General discussion

The present study was designed to 1) characterize handwriting quality and speed in a group of adults with ASD, compared with two control groups, and 2) analyze the impact of several factors on handwriting quality and speed.

Results showed that adults with ASD had poorer handwriting quality than both the control groups (CA and DA). Compared with the CA control group, adults with ASD wrote with more irregularities in height and less fluidity, and had difficulty with the spatial arrangement of the words. Compared with the DA control group, adults with ASD had greater difficulty correctly forming the letters (more distortions and ambiguity), and wrote words with more irregularities in their spatial arrangement. Previous studies had reported similar results for children and adolescents with ASD (Fuentes et al., 2010; Hellinckx et al., 2013), who exhibited difficulty with letter formation and spatial organization. The one previous study of handwriting in adults with ASD had restricted its investigation to measuring letter height in a pen and paper analysis (Beversdorf et al. 2001). Results indicated that each letter was larger (macrographia) than in the control group, which was not something we found in our study. This discrepancy may have been due to differences in sample size, the level of the participants with ASD, and study design. The sample in Beversdorf et al. (2001)'s study was composed of 10 adults with ASD described as "high functioning", whereas ours included 21 adults with high-functioning autism and Asperger syndrome, which could explain the lack of macrographia in our study. Moreover, Beversdorf et al. (2001) administered a written recall task, where the height of six letters (upper- and lowercase) was measured. Although macrographia was not identified as a feature of the handwriting of the adults with ASD in our study, letter size was found to be inconsistent (e.g., the letter "*e*" was as large, if not larger, than the letter "l"). This result shows that the quality of the handwriting produced by the adults with ASD in our sample reflected atypical development, rather than a developmental delay.

Regarding handwriting speed, the adults with ASD wrote fewer letters in 5 minutes than participants in the CA group, but the same number as those in the DA group. The same pattern of handwriting speed had previously been observed in children with ASD (Cartmill et al., 2009; Hellinckx et al., 2013). Whereas Cartmill et al. (2009) found no difference in production speed between children with ASD and TD children matched on CA and IQ, Hellinckx et al. (2013) did find a difference between children with ASD and TD children matched on CA, but not on IQ. This result shows that the adults with ASD in our sample were developmentally delayed in terms of handwriting speed.

The differences we observed in handwriting quality and speed between our ASD group and the two control groups (DA and CA) suggest that adults with ASD have a particular profile, with a mismatch between the levels of handwriting quality and speed. The adults with ASD wrote just as fast as the DA group, but their handwriting quality was poorer. This result can be explained by the automation of graphomotor gestures, which enabled them to increase their handwriting speed to the detriment of handwriting quality, resulting in less well-formed letters.

The second aim of the present study was to determine which factors predicted handwriting quality and speed in the ASD group, compared with the two control groups. First, analysis of perceptual-motor scores showed an effect of group for each factor, indicating that the adults with ASD performed worse than their TD peers matched on either CA or DA, with deficits in finger dexterity, visuomotor integration time, visual attention, fine motor coordination and graphomotor skills-a finding consistent with a previous report (Fournier et al., 2010). These factors are known to play a key role in handwriting acquisition in both TD children and those with ASD (Kushki et al., 2011).

In the adults with ASD, a simple linear regression analysis highlighted a significant influence of finger dexterity, graphomotor skills and visuomotor integration on handwriting quality, indicating that good hand-eye coordination, finger isolation and graphomotor activity promote handwriting quality in adults with ASD. These results are similar to those observed in the literature for both TD children (Marr et al., 2001; Van Hoorn et al., 2010) and those with ASD (Fuentes et al., 2009; Hellinckx et al., 2013; Kushki et al., 2011). Although multiple regression analyses failed to show that any of these factors predicted handwriting quality in ASD, they did reveal that DA plays a leading role in handwriting quality, as it explained 55% of the variance. These results indicate that although perceptual-motor factors influence handwriting quality in adults with ASD, they have no predictive value. Further studies are needed to identify and test other possible predictive factors for handwriting quality in ASD in adulthood, to better understand the nature of handwriting difficulties and be able to remedy them.

Given that DA was closely correlated with handwriting quality in our ASD sample, these results underscore the importance of cognitive skills for handwriting quality in adults with ASD. In the TD adults matched on CA, none of the variables we studied predicted handwriting quality. This observation can be explained by the high degree of handwriting automation in normal adulthood (Bourdin et al., 2010), which allows adults to reduce their cognitive load when implementing the automated low-level processes required for handwriting. Furthermore, because there is no assessment tool for adults, we had to administer the NEPSY, a tool designed for use with children, which may have resulted in a ceiling effect in adult controls. In the TD group matched on DA, visuomotor integration was the best predictor of handwriting quality, as it was in the study by Hellinckx et al. (2013). These results show that the factors influencing handwriting quality are more or less similar across adults and children with ASD, with any differences lying in their predominance and predictive weight.

Our study did not identify any predictive factors for handwriting speed in the ASD group. By contrast, Hellinckx et al. (2013) highlighted several factors (age, sex, reading skills, and manual dexterity) that predicted handwriting speed in children with ASD. In adults with ASD, these factors do not seem to have this effect. Reading skills, which predict handwriting speed in children with ASD, were not tested in our study, as we were interested solely in how perceptual-motor skills can help us understand handwriting performances in adults with ASD. We tested finger dexterity instead of manual dexterity because it appears to be a more influential factor in typical development (Van Hoorn et al., 2010).

Future studies should try to test other potential predictive factors for handwriting speed in adults with ASD.

In both control groups, several factors predicted handwriting speed, namely overall visual attention for the CA group, and graphomotor skills, visual attention time and pen grasp for the DA group. The finding that overall visual attention significantly correlated with handwriting speed in the CA group, and visual attention time significantly correlated with handwriting speed in both the CA and DA groups, is surprising for two reasons. First, visual attention time was the only factor that was common to the two control groups. Moreover, visual attention, in particular the time needed to find the visual stimuli, became more closely linked to the handwriting product with age. Second, studies in TD children (Malloy-Miller et al., 1995) and children with ASD (Fuentes et al., 2009; Hellinckx et al., 2013) had failed to find a link between handwriting performance and visual perception. Although the role of visual perception in the planning and execution of the written product is undeniable, studies have shown that its use declines across handwriting development (Ziviani & Wallen, 2006). However, no study has so far investigated the impact of visual perception on handwriting in adulthood.

The aim of the present study was to determine the characteristics of handwriting in adults with ASD and to identify predictive factors for handwriting quality and speed in this population, compared with two control groups. Our results showed that handwriting difficulties persist in adults with ASD, in terms of letter formation and spatial arrangement, compared with TD adults matched on CA or DA. DA is correlated with and, to a large extent, explains handwriting quality in adults with ASD. The handwriting speed of our sample of adults with ASD was similar to that of TD individuals matched on DA, but slower than that of control adults matched on CA, suggesting that the handwriting speed of individuals with ASD increases in adulthood. Our study measured handwriting quality during a copy task, where instruction specified to the participants was to write as they usually did, and not as neatly as possible, in order that the handwriting output was representative of what they frequently do. But it would also be interesting to evaluate handwriting quality in other contexts, asking participants to copy a text either for their own benefit (note-keeping focus) or for others (communicative focus). Thus, we could determine if the aim of the text produced influences handwriting quality. It is possible that when the production is intended for others (communicative focus), participants improve their handwriting quality, probably at the expense of handwriting speed, compared to the production for their own benefit. Indeed, the writing context influences handwriting quality and speed (Feder & Majnemer, 2007, for a review).

Moreover, with a better understanding of handwriting difficulties in adults with ASD, and the factors contributing to these difficulties, specific interventions can therefore be designed. Given the inclusion policies adopted in several countries worldwide, studies of handwriting in adults with ASD are clearly necessary. Research is also needed to explore the kinematics of handwriting movements in adults with ASD, given that it has so far only been studied in children with ASD (Johnson, Papadopoulos et al., 2013; Johnson, Phillips et al., 2013; Rosenblum et al., 2015). Future research will also need to test methods of handwriting remediation in children and adults with ASD, as some researchers have begun to do with writing guides (Johnson et al., 2015). These studies could explore the contribution of multimodal assessments of handwriting, which are already carried out among TD students (Bara & Gentaz, 2011; Vinter & Chartrel, 2010), in order to establish recommendations for learning and remediation. Low-level processes influence high-level ones (writing production) not just during childhood but also in adulthood. It is important to understand these low-level processes if we want to promote the social inclusion and employment of individuals with ASD. Moreover, the use of keyboarding to write may improve the writing production of children with ASD by limiting their handwriting difficulties (Ashburner, Ziviani, & Pennington, 2012; Dumont & Boyer, 2015). This tool may improve both quality and speed, although other studies should be conducted to try to better understand the contribution of keyboard use not only in children with ASD, but also in adolescents and adults with ASD.

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Conflict of interest

The authors of this manuscript have no conflict of interest.

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