Handwriting and Attention in Children and Adults with Attention Deficit Hyperactivity Disorder

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Adverse effects of drug therapy on handwriting fluency attributed to increased attentional control have been observed in children with attention deficit hyperactivity disorder (ADHD). The writing performance of 8 children with ADHD was assessed using a digitizing tablet in a double-blind, placebo-controlled test. Participants wrote a phrase in cursive script both on and off stimulant medication writing normally, writing with eyes closed, and writing faster than normal. Medication reduced fluency of normal handwriting movements. When children with ADHD were instructed to write faster than normal or with eyes closed, however, more fluent and even automated movements resulted, even on medication. We also assessed 10 children with ADHD, 10 children without ADHD, 10 adults with ADHD, and 10 adults without ADHD. Participants with ADHD were assessed both on and off medication. Children with ADHD on medication were less fluent than children without ADHD. Without medication, children with ADHD did not differ from children without ADHD; those on medication showed increased handwriting dysfluency. There was no significant difference between the adults. Both children and adults with ADHD could perform age-appropriate and automated handwriting movements. Children with ADHD on medication, however, gave more attention to the writing process, possibly hampering fluent handwriting movements.

Key Words: methylphenidate, automated movements, stimulant medication

Attention deficit hyperactivity disorder (ADHD) is the most commonly diagnosed behavioral disorder of childhood. The prevalence of the various subtypes of ADHD according to the Diagnostic and Statistical Manual of Mental Disorders, fourth edition (DSM-IV) criteria, namely the primarily inattentive, primarily hyperactive and the combined subtypes, varies between 3.4 and 4.7% (Wolraich, Hannah, Pinnock, Baumgaertel, & Brown, 1996). The core symptoms of the disorder...
include a developmentally inappropriate level of motor restlessness, inattention, and impulsiveness. These symptoms often result in an inability among children with ADHD to pay attention to the content of lessons. Difficulties at school are often the reason for the initial referral for evaluation.

Since poor handwriting in children with ADHD often contributes to academic failure (Barkley, 1998), several studies have examined the effects of stimulant drug therapy, which is the common pharmacological treatment of ADHD (Hoza & Pelham, 1993), on handwriting performance. It has been reported that stimulant medication has beneficial effects on qualitative aspects of handwriting such as legibility and accuracy including form, alignment, spacing, and uniformity of handwriting (Whalen, Henker, & Finck, 1981; Tucha & Lange, 2001). The results of a previous study, however, have demonstrated that kinematic aspects of handwriting performance in children with ADHD are adversely affected by stimulant therapy using methylphenidate (Tucha & Lange, 2001). Although the performance of boys with ADHD following withdrawal of stimulant medication did not differ from boys without ADHD with respect to the kinematics of handwriting, a marked deterioration in handwriting fluency was observed in the boys with ADHD following administration of their usual medication. In addition, boys with ADHD displayed lower maximum velocities and accelerations when they were on medication than following the withdrawal of the drug. It has been assumed that the disturbance of handwriting fluency following medication results from a secondary effect of stimulant drug treatment and that the medication-induced disturbance of handwriting fluency could be the result of an improvement in the ability to focus attention. The positive effects of stimulant medication might enable children with ADHD to focus attention on their handwriting to control movement execution. The conscious control of handwriting, necessary to write neatly, interferes with fluent or automated handwriting processes. The desire of children with ADHD to write neatly could be the result of emphasis placed on accurate handwriting by teachers.

One possible approach in examining whether the disturbance of handwriting fluency of children with ADHD on stimulant medication is caused by increased attentional control of movements (secondary effect) or by direct effects of the drug is to elicit fluent or even fully automated movements of children with ADHD when they are on their usual pharmacological treatment. Another strategy is to examine both children and adults with ADHD on and off medication. If the assumption of a secondary effect of medication is correct, one could expect that although children display a pattern of results as described above, adults with ADHD would show no disturbances of handwriting fluency, either on medication or following withdrawal of the drug since neatness of handwriting is less important in adulthood than in childhood. In an unpublished study on the factors associated with good handwriting, we observed that adults are significantly less concerned than children regarding the quality of their handwriting including aspects of legibility, regularity, neatness, and aesthetic details. In the present study, both approaches were used. In the first experiment, we attempted to elicit fluent handwriting movements of children with ADHD when they are on their usual pharmacological treatment (first approach). In the second experiment, handwriting movements of both children and adults with ADHD on and off medication was assessed (second approach).
Experiment 1

Participants and Procedure
In a double-blind, placebo-controlled examination, the writing performance of 8 right-handed children (3 girls, 5 boys; mean age = 10.50 years, \(SEM = .42\) years; mean education = 4.50 years, \(SEM = .42\) years) with a diagnosed ADHD according to the DSM-IV criteria was assessed. None of the children suffered from another clinical syndrome. At the time of the study, all children with ADHD were being treated with stimulant medication using methylphenidate (mean total dose = 23.75 mg/day, \(SEM = 2.27\) mg). The participants were asked to write the phrase “Ein helles grelles Licht” (“A bright and glaring light”) in cursive script both on the usual stimulant medication and following withdrawal of the drug under three different conditions. The conditions consisted of (a) normal writing, (b) writing with eyes closed, and (c) writing faster than normal. The sequence of conditions was randomly assigned to participants. The phrase was written five times per participant. Before the start of these writing tasks, several practice trials were undertaken to allow the participants to become accustomed to the writing tablet. Neither spatial constraints nor restrictions of posture, speed, or size of writing were imposed. Half of the children were tested first on stimulant medication and then on a placebo. The remaining children were tested in the reversed order. The children were randomly assigned to the starting condition. Handwriting of the children on stimulant medication was assessed approximately 1 hr after administration of the usual medication. In the placebo condition, the mean time to the last medication was approximately 12 hr. The time period between testing and retesting was 1 week. In all the tasks, the participants received the standard instruction, as usual in this type of research, to write as quickly and naturally as possible.

Apparatus and Analysis
Handwriting movement samples were recorded in a laboratory room with constant temperature, noise, and illumination levels using a digitizing tablet (Wacom IV, Wacom, Munich, Germany) with a special pen containing a normal ink refill. The position of the pen on the tablet, velocity, and acceleration were measured continuously during writing. The digitizing tablet had a maximum sampling rate of 200 Hz. Data were stored on a personal computer connected to the tablet. The pen’s tip could be localized in both axes (\(x/y\)) with an accuracy of .2 mm. In addition, movements of the pen tip above the paper, up to a maximum of 1.3 cm, could also be recorded. Data was analyzed with a computational program for the analysis of handwriting movements (Mai & Marquardt, 1992). Kinematic data were calculated and smoothed using the nonparametric regression methods (nonparametric kernel estimation) devised by Marquardt and Mai (1994). The tablet was constructed to resemble a common desk pad in order that participants could produce their usual handwriting.

Analysis of Handwriting
For analysis, the mean number of inversions of the direction of the velocity (NIV) profiles of the letter combination “ll” of the German words “helles” (bright) and
“grelles” (glaring) was calculated. Kinematic analysis of the letter combination “ll” was performed, since the examination of the dynamic and static writing trace could often require its segmentation into meaningful units. From a motor viewpoint, single letters, and, in particular, single strokes are the smallest relevant units of the handwriting movement (Thomassen & Van Galen, 1992). The letter combination “ll” was chosen since these letters represent a simple letter combination usually executed in script. Furthermore, while writing the letter combination “ll,” the pen remains in contact with the tablet. Data analysis focused on the vertical component of the strokes. The NIV of the velocity profiles was chosen as a measure of automation, since automated and nonautomated handwriting movements can be distinguished from one another by profiles of velocity (Meulenbroek & Van Galen, 1989; Tucha, Paul, & Lange, 2001). More fluent handwriting movements are reflected in a smaller NIV (Mai & Marquardt, 1992; Tucha, Aschenbrenner, & Lange, 2000). Kinematic analysis was performed for each phrase. For further analysis, mean scores were calculated for each participant. Statistical analysis was performed using the Friedman and Wilcoxon tests. For statistical analysis, an alpha level of .05 was applied.

**Results**

Using the Friedman test, statistical analysis of the NIV in children with ADHD revealed a significant difference between writing conditions ($\chi^2 = 27.24; df = 5$;
p < .001) (Figure 1). Subsequent post hoc analysis using Wilcoxon tests revealed that, in contrast to the placebo, medication with methylphenidate resulted in a reduced fluency of normal handwriting movements as indicated by an increased NIV (Z = –2.52; p = .012). When children with ADHD were instructed to write faster than normal or to write with closed eyes, however, more fluent and even automated handwriting movements could be elicited, even though the children were on medication. Regarding the NIV, significant differences were found between normal handwriting on medication and both writing with closed eyes (Z = –2.54; p = .011) and writing faster than normal (Z = –2.53; p = .012). No differences were observed between the NIV during normal handwriting off medication and the NIV both during writing with closed eyes off medication (Z = –1.13; p = .257) and during writing faster than normal off medication (Z = –1.78; p = .075). The comparison between the NIV during writing with closed eyes on medication and off medication revealed no difference (Z = –1.07; p = .287). In addition, no differences were observed in the NIV during writing faster than normal on medication and off medication (Z = –1.28; p = .202).

Experiment 2

Participants and Procedure

In a double-blind, placebo-controlled examination, the writing performance of 10 right-handed children (5 girls, 5 boys; mean age = 9.90 years, SEM = .28 years; mean education = 3.90 years, SEM = .28 years) with a diagnosed ADHD according to the DSM-IV criteria who did not participate in the first experiment was assessed. At the time of the study, all children with ADHD were being treated with stimulant medication (mean total dose = 22.00 mg/day, SEM = 2.00 mg). Children with ADHD were asked to write the same phrase as in the first experiment both on the usual pharmacological treatment and following the withdrawal of stimulant medication. Each phrase was written 5 times per participant. Half of the children with ADHD were tested first on stimulant medication and then following withdrawal of the drug; the remaining children were examined in the reverse order. Children were randomly assigned to a condition. The control group consisted of 10 right-handed sex-, education- and age-matched children without ADHD (5 girls, 5 boys; mean age = 9.90 years, SEM = .27 years; mean education = 3.90 years, SEM = .27 years). In addition, the handwriting performance of 10 right-handed adults (5 female, 5 male; mean age = 33.80 years, SEM = 1.84 years; mean education = 10.30 years, SEM = .47 years) with ADHD was assessed both on their usual pharmacological treatment (mean total dose = 23.00 mg/day, SEM = 2.26 mg) and following the withdrawal of medication. All met the DSM-IV criteria for ADHD devised by Barkley and Murphy (1998), including the retrospective diagnosis of an ADHD in childhood (DSM-IV criteria) and current symptoms. None of the adults had previously been diagnosed with ADHD or received stimulant therapy at any time in the past. Furthermore, 10 right-handed sex-, education- and age-matched adults without ADHD participated in the experiment (5 female, 5 male; mean age = 33.60 years, SEM = 1.93 years; mean education = 10.10 years, SEM = .50 years). The handwriting of both children
and adults with ADHD on stimulant medication was assessed approximately 1 hr after administration of the usual medication. In the placebo-condition, the mean time to the last medication was approximately 12 hr. The time period between testing and retesting was 1 week in children with ADHD and approximately 23 weeks in adults with ADHD (mean time = 23.20 weeks, \( SEM = 4.06 \)). None of the participants were taking concurrent psychotropic medication at the time of the study (e.g. antidepressants) or suffered from another clinical syndrome. None of the participants without ADHD had any history of neurological or psychiatric disease or were taking medication known to affect the central nervous system. Parents of children and participants gave informed consent to the study. Data recording and analysis were performed as described in Experiment 1.

**Results**

Using the Friedman test, analysis of the NIV in children revealed a significant difference \( \chi^2 = 12.84; df = 2; p = .002 \) (Figure 2). Subsequent post hoc analysis using Wilcoxon tests showed that children with ADHD on stimulant medication displayed significantly more inversions in the direction of their velocity profiles

![Figure 2—Number of inversions in velocity per stroke (NIV) of children and adults with and without ADHD.](image-url)
than children without ADHD ($Z = -2.70; p = .007$). Following withdrawal of the drug, children with ADHD did not differ from children without ADHD in the NIV ($Z = -1.19; p = .233$). Statistical comparison regarding the NIV of children with ADHD on and off stimulant medication demonstrated that the medication resulted in an increased dysfluency during handwriting, as indicated by a higher NIV ($Z = -2.81; p = .005$). Statistical comparison using the Friedman test between adults without ADHD and adults with ADHD on and off stimulant medication did not reach significance ($\chi^2 = 3.00; df = 2; p = .223$).

**Discussion**

The results of the present experiments are in accord with the findings of a previous study (Tucha & Lange, 2001) which reported that stimulant medication adversely affects the handwriting performance of children with ADHD. Furthermore, the present experiments support the proposition that the stimulant-induced impairment of handwriting movements is the result of a secondary attention-enhancing effect (Tucha & Lange, 2001). Previous studies have demonstrated that treatment of children with ADHD using methylphenidate resulted in marked improvements of attention functions including vigilance (Riccio, Waldrop, Reynolds, & Lowe, 2001), tonic and phasic alertness (Cohen, Douglas, & Morgenstern, 1971; Reid & Borkowski, 1984; Sykes, Douglas, & Morgenstern, 1972), divided attention (Keith & Engineer, 1991), flexibility/shifting of attention (Kempton et al., 1999) and aspects of selective attention such as inhibition (Tannock, Schachar, Carr, Chajczyk, & Logan, 1989; Van der Meere, Gunning, & Stemerding, 1999) and focused attention (Musten, Firestone, Pisterman, Bennett, & Mercer, 1997).

In the first experiment, fluent execution of handwriting movements could easily be elicited in children with ADHD on their usual medication. Although these children were not able to produce automated movements during normal writing of a short phrase, they performed fluent and even automated handwriting movements in the same test session when instructed to write with closed eyes or to write faster than usual. These findings indicate that when attentional control of writing is prevented by the use of simple verbal instructions, children with ADHD on stimulant medication can perform fluent writing movements. According to these findings, the disturbed movements during normal handwriting in children with ADHD on stimulant medication cannot be attributed to medication-induced peripheral changes or alterations of brain states. Furthermore, the result of the second experiment also contradicts the proposition of a primary effect of stimulant medication on handwriting fluency. If stimulant drug therapy directly impairs movement execution, one would expect both children and adults with ADHD on stimulant medication to show a deterioration in handwriting fluency. In adults with ADHD, however, no deterioration of handwriting fluency was observed. Since the findings of an unpublished study demonstrated that adults are significantly less concerned with neat handwriting than children, these findings support the proposition that the impairment of handwriting fluency in children with ADHD on medication could result from the desire to write neatly to please teachers or parents. This conclusion should be interpreted as a hypothesis generated from
the study and needs further investigation. In addition, the conclusions drawn from the second experiment are limited since different criteria are defined for the diagnosis of ADHD in childhood and adulthood. In addition, the sample of adults with ADHD probably constitutes only a subgroup of the population of children with ADHD. Although a marked reduction of ADHD symptoms from childhood to adulthood has been observed (Biederman, Mick, & Faraone, 2000; Hechtman, 1992; Klein & Mannuzza, 1991), the symptoms of ADHD persist into adulthood in almost 30 to 70% of children with ADHD (Katz, Wood, Goldstein, Auchenbach, & Geckle, 1998; Walker, Shores, Trollor, Lee, & Sachdev, 2000). In the framework of a prospective longitudinal study, Mannuzza and colleagues (1998) found a DSM-III-R diagnosis in adulthood in 4 to 8% of their original sample of hyperactive boys. Therefore, since adults who suffered from ADHD in childhood and whose symptoms did not persist into adulthood did not enter the adult sample, only those adults who continue to display symptoms of ADHD were considered in the present study.

**Conclusion**

The findings of both the present experiments and our previous study indicate that neither children nor adults with ADHD have disturbances of handwriting movements per se. They were able to perform age-appropriate and automated handwriting movements. Children with ADHD on methylphenidate, however, gave more conscious attention to the writing process. Although their handwriting improved in accuracy and legibility, their fluency in handwriting deteriorated. The intention to write more neatly might therefore interfere with the production of fluent or automated handwriting. These conclusions are restricted to individuals with ADHD without psychiatric comorbidity. Both children and adults with ADHD have often been found to suffer from additional psychiatric disorders. The rates of comorbidity reported vary according to selection criteria and assessment techniques used for data collection (Jensen, Martin, & Cantwell, 1997). About 44% of children with ADHD appear to suffer from at least one additional psychiatric disorder with about 32% of children with ADHD fulfilling the criteria of two psychiatric conditions. About 11% of children with ADHD have three or more other psychiatric disorders (Szatmari, Offord, & Boyle, 1989). Of the children with ADHD who were clinically referred, 87% meet diagnostic criteria of at least one other psychiatric disorder, with 67% having at least two other psychiatric disorders (Kadesjo & Gillberg, 2001). Some children with ADHD might also show symptoms of developmental discoordination disorder which is characterized by fast, fluent, and inaccurate movements (Geuze, Jongmans, Schoemaker, & Smits-Engelsman, 2001; Smits-Engelsman, Niemeijer, & Van Galen, 2001; Jongmans, Smits-Engelsman, & Schoemaker, 2003; Schoemaker, Smits-Engelsman, & Jongmans, 2003). In adults with ADHD, Biederman and colleagues (1993) found that 77% of their sample of referred and nonreferred adults with ADHD met diagnostic criteria for at least one additional psychiatric disorder. Approximately 20% of adults with ADHD meet diagnostic criteria of two or more psychiatric diseases.
References


