The impact of spatio-temporal constraints on cursive letter handwriting in children

Estelle Chartrel, Annie Vinter*

University of Bourgogne, Laboratoire d'Etude de l'Apprentissage et du Développement (LEAD), Centre National de la Recherche Scientifique (CNRS), Pôle AAFE, Esplanade Erasme, BP 26513, 21065 Dijon Cedex, France

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Abstract

The study assessed the impact of spatial and temporal constraints on handwriting movements in young children. One hundred children of 5–7 years of age of both genders were given the task of copying isolated cursive letters under four conditions: normal, with temporal, spatial, or spatio-temporal constraints. The results showed that imposing spatio-temporal constraints on handwriting movements affected 5-year-olds’ performance, at least for a subset of letters (those with the simplest shapes). The constraints probably enabled young children to free themselves from the models and helped them to better program their movements.

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1. Introduction

Mastering handwriting skills is extremely important to children’s academic advancement. A body of research has shown that when children experience difficulties in the very act of performing handwriting movements, they encounter difficulties in the process of writing, in producing texts for instance (Berninger, 1999; Graham, 1990; Graham, Harris, & Fink, 2000). As long as letter production is not automatized, producing handwriting movement requires memory and attentional resources, which, in turn, constrains the cognitive processes involved in higher levels, such as expressing ideas and composing texts (Jones & Christensen, 1999). It is for this reason that an investigation of the different factors that may facilitate handwriting movement programming is of particular interest. The present study investigated the role spatio-temporal constraints may play in kinematical aspects of handwriting movements in young children.

Handwriting is a skill that requires control over fine movements of the hand and fingers and develops through a long and complex process, to which schooling and the child’s motor, perceptual, and cognitive developments contribute (Chartrel & Vinter, 2004; Thomassen & Teulings, 1983; Van Galen, 1991; Zesiger, 1995). Two types of movements are involved in handwriting: those responsible for the production of the shapes of the letters and those enabling the spatial layout of the characters on the page, corresponding to the morphokinetic and topokinetic components.

* Corresponding author.
E-mail address: annie.vinter@u-bourgogne.fr (A. Vinter).
respectively (Paillard, 1974, 1990). In adults, while the topokinetic component, under feedback control, relies heavily on sensorial information feedback, the production of morphokinetic movements, under feedforward control, is governed by motor programs (Paillard, 1976; Smyth & Silvers, 1987; Teasdale et al., 1993; Van Galen, Smyth, Meulenbroek, & Hylkema, 1989). The development of the motor programs dedicated to the production of letters is very gradual. Indeed, we have shown that whereas, in adults, the movements producing cursive letters remained invariant when visual information was absent, these movements underwent many modifications in 10-year-old children, thus indicating that the production of the morphokinetic components was still not automatic at that age (Chartrel & Vinter, 2006). The development of handwriting is therefore based to a large extent on the gradual switch from a mode of feedback control to a mode of feedforward control of movements (Meulenbroek & Van Galen, 1988; Zesiger, 1995).

Motor maturity is also a critical factor in this development: the production of expert handwriting requires the coordination of proximal and distal articulations (de Ajuriaguerra et al., 1964). The former are essentially responsible for the production of the topokineses, while the latter are predominantly involved in the production of the morphokinetic components, in the context of normal-sized handwriting. However, these two types of articulation do not develop synchronously. The first, controlling large-amplitude movements mature much earlier than the second, which are involved in small-amplitude movements. Thus, when children start to learn cursive shapes, at about 5–6 years of age, they rely strongly on visual control and produce large-amplitude movements that are slow and not fluent. Later, thanks to the formation of motor programs and to the distal maturity, their movements gain speed and fluency and decrease in amplitude (Meulenbroek & Van Galen, 1988; Mojet, 1991; Zesiger, 1995). This development shares many common features with other perceptual–motor skills, such as pointing (Badan, Hauert, & Mounoud, 2000; Hay, 1978, 1979, 1984), or drawing (Van Mier, 2006).

If motor performance undergoes a long period of development, the same is also true for the quality of the written trace (de Ajuriaguerra et al., 1964). Karlsdottir and Stefansson (2002) carried out a longitudinal study over 5 years, during which they performed a qualitative analysis of the written productions of 407 children. This analysis revealed that, unsurprisingly given the powerful law of practice, the handwriting quality improved greatly during the first year of learning and much more slowly after that. However, the authors reported that this development profile characterized children who were good at writing. In fact, the quality of the written productions of children who were bad at writing increased steadily over the 5 school years examined. The same study showed a linear increase in letter writing frequency (number of letters per minute) over the 5 years of learning, for both good and bad writers.

Regarding the development of the size of the written traces, Auzias, Casati, Cellier, Delaye, and Verleure (1977) revealed that the average size of the handwriting produced naturally by children is 8 mm between the age of 4 and 5 years 6 months and drops to 4 or 5 mm just before children are systematically introduced to handwriting learning. de Ajuriaguerra and Auzias (1960) reported that kindergarten teachers require the children (5 years of age) to go from 5 mm to 4 mm and then to 3 mm by the end of the school year. More recently, Charles, Soppelsa, and Albaret (2004), in their study linked to the French adaptation of the Concise Assessment Scale for Children’s Handwriting (known by the acronym BHK), confirmed that the handwriting of children in the first grade of primary school is much larger than that requested by teachers, and that it decreases in size mainly between the first and second grade.

If handwriting velocity and size are the outcome of a long development of the motor control of distal movements, it would be interesting to investigate the potential effect on handwriting movements of constraints imposed on the child, in particular temporal (speed) and spatial (size) constraints. Meulenbroek and Van Galen (1986) studied the impact of time and size constraints on the production of repetitive patterns (garlands, waves, zigzags, etc.) by children of 7–9 years of age. Their results indicated that the instruction to increase speed induced a decrease in movement time and length, as well as an improvement in the quality of the production, revealed by an increase in the signal/noise ratio. Conversely, when the size of the traces was imposed, they observed an increase in movement time as well as deterioration in writing quality. Finally, their study also showed that the combination of a time and size constraints improved children’s performance by leading to a greater increase in speed and better signal quality. The modifications resulting from the spatial and/or temporal constraints were identical from 7 to 9 years of age.

The present paper extends Meulenbroek and Van Galen’s (1986) work by examining younger children and by testing them in an unfamiliar task, relevant to school, namely cursive letter. We hypothesised that the absence of age effect in the Meulenbroek and Van Galen (1986) study was in part due to the type of graphic task used, which was familiar to children aged 7–9 years (producing garlands, waves, zigzags, etc.). We predicted that imposing temporal and spatial constraints on a cursive letter writing task presented to young children should reveal age effects.
Performance of 5-year-old children, who had not yet started systematic learning of cursive writing, was compared with that of 6- and 7-year-old children, who had been trained on copying isolated letters. Indeed, it is essentially during the period when handwriting starts to be taught (6–7 years of age) that the issue of temporal and spatial constraints arises. In accordance with earlier data (Meulenbroek & Van Galen, 1988, 1989; Zesiger, 1995), we predicted that in a spontaneous, not constrained handwriting condition, there will be a decrease in the length of the writing trajectories and in the number of velocity peaks, as well as an increase in speed, between 5 and 7 years of age (Hypothesis 1). We also expected an effect in the above movement parameters when temporal constraints (instruction to increase the writing speed) and/or spatial constraints (imposing writing between lines) were introduced. Specifically, we expected that the effects of the different constraints should differ as a function of age, with a stronger impact on the performance of younger children than on that of older children (Hypothesis 2). Although school teachers impose principally, if not solely, spatial constraints on children’s handwriting movements, we expected similar improvement of handwriting production under temporal constraints (Hypothesis 3).

2. Method

2.1. Participants

The 100 right-handed children taking part in this study were divided into three groups according to their age and school level. The mean age of the children in the last year of the kindergarten was 5 years 8 months (from 5 years 3 months to 6 years 2 months, SD = 0.46; n = 27, 15 girls and 12 boys); of children in first grade, it was 6 years 7 months (from 6 years 3 months to 7 years, SD = 0.54; n = 30, 18 girls and 22 boys) and of children in second grade, it was 7 years 10 months (from 7 years 2 months to 8 years 2 months, SD = 0.49; n = 33, 15 girls and 18 boys).

Handedness was assessed by testing children on eight items from the Bryden (1997) test, four unimanual (drawing, throwing a ball, holding scissors and brushing teeth) and four bimanual (closing a bottle, hitting a nail with a hammer, lighting a match, and drying a plate with a napkin). Only children who obtained a score equal to or greater than 6 were selected. None of the selected children used their left hand or hesitated between the two hands for writing. They were native French speakers, from middle class families, and their sight was normal or corrected. They showed neither scholastic delay nor advance. In order to avoid excessive testing, and still obtain data for the 26 letters, the children were randomly assigned to a subset of letters (six or seven), equivalent in terms of types of trajectory (see Procedure). The experiment took place at the same time in the school year for the various groups and before the youngest children (the last year of kindergarten) had received any formal instruction in cursive writing. Written informed consent was provided by parents for each child.

2.2. Material

The handwriting productions were collected using protocols developed for the needs of the experiment. One single sheet of paper allowed 12 copies of the same letter to be collected. On this sheet, the model of the letter to be produced was printed, first, on a baseline and then between two lines. These were central lines 3 mm apart (inside which letters were produced without pen lift). The corners of the sheet allowed 12 copies of the same letter to be collected. The size in writing exercise books: 3 mm for letters without vertical extensions and 8 mm for the other letters, except for f (13 mm).

The 26 letters of the alphabet were divided into four sets, equivalent with respect to the type of motor work they required, using data collected in adults (Chartrel, 2006). In this study, 30 adults had been asked to classify the 26 letters according to the proprioceptive similarity of their writing trajectory. The participants had to imagine that they were actually writing the letters in order to identify which letters had similar proprioceptive “images”. The percentages of association between pairs of letters were calculated and the association matrix thus obtained was analysed by means of a cluster analysis using an ascending hierarchical classification algorithm. Four clusters resulted from this statistical analysis: Cluster 1: b, l, f, h, k; Cluster 2: i, m, w, t, n, u, v; Cluster 3: g, r, p, z, j, s, y, x; and Cluster 4: a, q, d, c, o, e. The letters were then divided into four sets such that each set of letters included letters from the four clusters: Set 1: a, b, g, i, m, r; Set 2: q, l, p, w, z, d; Set 3: c, f, j, t, n, s, o; and Set 4: e, h, y, u, v, k. Letter x was excluded because it could not be produced without pen lift.
Children’s handwriting movements were recorded using a graphics tablet (Wacom Intuos2 A4) linked to a PC computer on which the program OASIS was installed (De Jong, Hulstijn, Kosterman, & Smits Engelsman, 1996) for data acquisition and analysis. The children wrote with a special pen (Intuos Ink Pen, Wacom), fitted with a device recording the axial force exercised on the paper. The position of the electronic pen’s tip, measured by its vertical and horizontal coordinates, was sampled at a frequency of 206 Hz, with a spatial resolution of ±0.15 mm. The data were filtered at a frequency of between 12 and 24 Hz by means of a Butterworth low-pass filter.

2.3. Procedure

Several days before the experiment started, we asked the children to write their first name and the day of the week in cursive writing, using a static model. The productions collected were then analysed according to four criteria from the BHK test (Charles et al., 2004): chaotic handwriting, unsteadiness, relative height of different letters, strange or ambiguous letters. A score of 0 was given when the criterion was not present in the word and a score of 1 when it was present; this was done for both words. The total scores obtained, ranging from 0 to 8, made it possible to define, within each age group, four groups of participants who were equivalent with respect to their initial handwriting abilities. These groups comprised a similar number of children with high, medium or poor initial capacities. The mean scores of these four groups ranged from 3.6 to 4 for 5-year-olds and did not differ significantly from one another. Specifically, G1/G2, t(12) = −0.38; G1/G3, t(12) = 0.30; G1/G4, t(13) = −0.20; G2/G3, t(10) = 0.58; G2/G4, t(11) = 0.27; G3/G4, t(11) = −0.45, p > 0.30. They also did not differ significantly from one another at 6 and 7 years. Specifically, G1/G2, t(19) = 0.26 and t(16) = 0.45, respectively; G1/G3, t(17) = 0.53 and t(15) = −0.38, respectively; G1/G4, t(18) = 0.66 and t(14) = −0.73, respectively; G2/G3, t(18) = 0.42 and t(15) = −0.48, respectively; G2/G4, t(19) = 0.58 and t(14) = −0.91, respectively; G3/G4, t(17) = 0.21 and t(13) = −0.66, p > 0.30, respectively. This analysis also allowed us to exclude children with handwriting difficulties (four in the last year of kindergarten, four in the first grade and one in the second grade). One set of letters was randomly assigned to each of these four groups of participants.

In the experiment, the child was given the task of copying the letter shown, three times in succession, under four writing conditions that involved spatial and/or temporal constraints. The experimenter insisted on the fact that the child had to reproduce the exact shape of the letter given in the model, even if the child was not accustomed to this exact form. The experimenter demonstrated several times to the younger children the trajectory associated with each letter. Each letter was thereafter produced 12 times. In the first baseline condition (Base), the handwriting speed and size was spontaneous. In the temporal constraint (Temp) condition, the child was asked to write as quickly as possible and still reproduce accurately the model. In the spatial constraint (Space) condition, the child was asked to write between interlines (size imposed). Finally, in the Temp—Space condition, there was a spatio-temporal constraint with the two previous constraints being combined (speed and size imposed). In order to achieve our goal, which was to assess the impact of spatio-temporal constraints on the handwriting movements, the first condition (Base) needed to be presented first. This made it possible to collect the children’s spontaneous production, free from the influence of the other writing instructions, and thus to define a baseline level for performance. The order of presentation for the three other conditions was randomized across participants. Finally, each of the children only worked on one of the sets of letters mentioned above, and the letters were presented randomly. The child was asked to produce the letter without lifting the pencil off the paper. The experimenter repeated the instructions several times and emphasized the importance of producing correct letter shapes. Children were prevented from increasing their speed too drastically in the Temp and Temp—Space conditions.

2.4. Data analysis

Depending on the set of letters they were assigned to, the children produced either 72 (Sets 1, 2 and 4) or 84 letters (Set 3). For each of them, we only kept the productions corresponding to an accurate reproduction of the model shape (no segment added or missing compared to the model). Out of all the data collected, approximately 15% were eliminated for this reason (10% at 5 years, 4% at 6 years and 1% at 7 years). In addition, the letters a, b, d, g, h, k, q were removed from the analysis, as too many children aged 5 years were not able to write them in a cursive style without lifting the pencil off the paper, and because letters g—h—k were often inaccurately reproduced under speed constraints. The results shown are therefore those obtained from a set of 18 letters, common to the three age groups. In order to analyse the handwriting movements, the following parameters were selected: length of the trajectories (centimetres),
velocity (centimetres/second), number of velocity peaks, and pressure (pressure levels of the Intuos Pen). For each variable, the average obtained over the three trials was computed and the analyses were carried out on these means. The number of velocity peaks, which is a movement fluency index, was divided by the number of strokes each letter contained, where a stroke corresponds to the portion of the trajectory contained between two inflection points of the curve \((c = 3; e = 3; f = 4; i = 2; j = 3; l = 3; m = 7; n = 5; o = 3; p = 5; r = 4; s = 3; t = 2; u = 4; v = 4; w = 6; y = 5; z = 6)\). The dots for the letters \(i\) and \(j\), and the dash of \(t\) were not taken into account. Thus, a completely fluent movement led to a weighted number of peaks equal to 1. We focused our interest on movement fluency parameter, and not on performance accuracy parameters, because this parameter is considered a good indicator of the formation of the motor programs (Zesiger, 1995).

3. Results

To begin with, ANOVAs were performed in order to study the effect of age on the mean values of the different parameters measured in the baseline writing condition. The purpose of these analyses was to isolate the developmental profile of the characteristics of handwriting movements between 5 and 7 years of age. Following this, for each of the parameters, the mean values obtained in each of the three constraint conditions were divided by the mean value measured in the baseline condition. Thus, the changes to the various parameters according to the constraints imposed were assessed with reference to the value 1. A ratio of less than 1 indicated a decrease of the parameter measured compared to the baseline condition, while a ratio greater than 1 indicated an increase. T-tests were run to compare the increase or decrease of the variable to the values observed in the Base condition. ANOVAs were also performed on these data with age (5–7 years old) as a between-subject factor and condition (Temp, Space, Temp–Space) as a within-subject factor. The effect sizes were also computed, and we retained for presentation only the differences with an effect size at least equal to 0.15 (Cohen, 1988).

3.1. Analysis of the movement parameters in the baseline condition

Fig. 1 shows how the mean trajectory length, velocity, pressure and the weighted mean number of velocity peaks evolved with age in the baseline writing condition.

The mean trajectory length (Fig. 1A) decreased with age, \(F(2, 97) = 109.4, p < 0.001, \text{ partial } \eta^2 = 0.69\), and this drop was mainly located between the age of 5 and 6 years, 4.97 cm vs. 2.93 cm, \(F(1, 97) = 149, p < 0.001, \text{ partial } \eta^2 = 0.60\). The size effects demonstrated the large impact of age on lengths. The results also highlighted a variation in velocity (Fig. 1B) with age, \(F(2, 97) = 32.9, p < 0.001, \text{ partial } \eta^2 = 0.40\). Velocity increased mainly between 6 (1.22 cm/sec) and 7 years of age (1.74 cm/sec), \(F(1, 97) = 36.2, p < 0.001, \text{ partial } \eta^2 = 0.27\). The mean number of velocity peaks per stroke (Fig. 1C) decreased steadily with age, \(F(2, 97) = 120.5, p < 0.001, \text{ partial } \eta^2 = 0.71\) reducing from 5.9 to 3.1 between 5 and 6 years of age, and then decreasing further to 1.8 at age 7. The effect size indicated the important role of age and, concomitantly, of handwriting practice. These results concerning the lengths, velocities and number of velocity peaks provide support to Hypothesis 1. Finally, pressure (Fig. 1D) also evolved with age, \(F(2, 97) = 11.03, p < 0.001, \text{ partial } \eta^2 = 0.18\). Initially unchanged between 5 and 6 years of age (\(M = 554, M = 545; F < 1\)), it tended to increase between 6 and 7 years of age (\(M = 648\)), \(F(1, 97) = 19.3, p < 0.001, \text{ partial } \eta^2 = 0.16\). Thus, with age, children’s handwriting movements gained velocity and fluency, and the writing size decreased, while pressure tended to increase.

3.2. Impact of the spatio-temporal constraints

Fig. 2 shows, by age and for each condition, the mean values for the trajectory length, velocity, weighted number of velocity peaks and pressure, plotted against the baseline writing condition. A value less than the reference value of 1 indicates a decrease for the parameter measured compared to the baseline condition, while a value greater than 1 indicates an increase for that parameter.

Fig. 2A reveals that the average length of the trajectories did not vary under the temporal constraint across age, while, as could be expected from the task instructions, the spatial and spatio-temporal constraints led to the lengths getting smaller. The main effect of condition was significant, \(F(2, 194) = 181.3, p < 0.001, \text{ partial } \eta^2 = 0.65\), as well as of Conditions by Age, \(F(4, 194) = 61.4, p < 0.001, \text{ partial } \eta^2 = 0.55\). As expected from Hypothesis 2, the decrease

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in the length of the trajectories, following the spatial and spatio-temporal constraints, was much greater at the age of 5 than at 6 and 7 years. Under the temporal constraint, the trajectory lengths did not change at the age of 5 years, in comparison to the Base condition, $t(26) = 0.92$, $p > 0.30$, while a significant decrease was observed at the ages of 6 and 7 years, $t(39) = -9.3$ and $t(32) = -5.9$, $p < 0.01$, respectively.

Fig. 2B shows a large variation in mean velocity according to the writing condition, $F(2, 194) = 290$, $p < 0.001$, partial $\eta^2 = 0.74$. As expected from Hypothesis 2, the significant Age $\times$ Condition interaction indicated that the differences between conditions were greater at the age of 5 years than at older ages, $F(4, 194) = 16.7$, $p < 0.001$, partial $\eta^2 = 0.25$. In the Space condition, velocity was close to that observed in the baseline writing condition, while, as requested by the task instructions, the temporal and spatio-temporal constraints led to an increase in velocity, greater under the former than the latter condition. The temporal constraint produced significant increase in velocity at all ages, 5 years: $t(26) = 14$; 6 years: $t(39) = 9.2$; 7 years: $t(32) = 14.6$, $p < 0.01$. However, under the Temp–Space condition, the velocity of the movements for the 5-year-old children remained unchanged, $t(26) = 0.75$, $p > 0.40$, while that for the 6- and 7-year-old children became higher, more so in the older children, $t(39) = 5.9$ and $t(32) = 8.8$, $p < 0.01$, respectively. The Space condition involved a decrease in velocity at the ages of 5 and 6 years, $t(26) = -8.8$ and $t(39) = -3.6$, $p < 0.01$, and no change at the age of 7 years, $t(32) = 0.80$, $p > 0.40$.

A significant main effect of Condition, depicted in Fig. 2C, showed that the temporal and spatio-temporal constraints led to a greater drop in the number of velocity peaks per stroke than the Space condition, which did not differ from the Base condition, $F(2, 194) = 219$, $p < 0.001$, partial $\eta^2 = 0.69$. As predicted by Hypothesis 3, movement
fluence, indexed by the decrease in the number of velocity peaks, improved at all ages in the two conditions where temporal constraints were imposed. Specifically, Temp condition: 5 years, $t(26) = -18.6, 6$ years, $t(39) = -16.4, 7$ years, $t(32) = -11.7, p < 0.01$; Temp–Space condition: 5 years, $t(26) = -18.6, 6$ years, $t(39) = -16.4, 7$ years, $t(32) = -11.7, p < 0.01$. However, contrary to Hypothesis 2 which predicted a greater impact of the constraints at 5 years than at 7 years, a significant interaction Age $\times$ Condition indicated that the differences between conditions were higher at the age of 6 years than in the other age groups, $F(4, 194) = 7.2, p < 0.001$, partial $\eta^2 = 0.13$. The Space condition resulted, at 5 and 7 years of age only, in a significant decrease in the number of velocity peaks, $t(26) = -5.9$ and $t(32) = -3.3, p < 0.01$, respectively.

The average pressure varied with writing condition, $F(2, 194) = 21, p < 0.001$, partial $\eta^2 = 0.18$, and the writing condition interacted with age, $F(4, 194) = 10, p < 0.001$, partial $\eta^2 = 0.17$. However, as Fig. 2D shows and as confirmed by the effect sizes, the differences were smaller in comparison to those observed in the other parameters. Nevertheless, the interaction showed again that the changes induced by the writing conditions were greater at 5 years than at the other ages, as postulated by Hypothesis 2. Indeed, at age 5, pressure decreased significantly in the Space and Temp–Space conditions in comparison to the Base condition, $t(26) = -7.1$ and $t(26) = -2.2, p < 0.05$, respectively, but was not modified in the Temp condition, $t(26) = 1.6, p > 0.20$. This parameter was stable at the ages of 6 and 7 years.

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Fig. 2. Average letter length (A), average velocity (B), average number of velocity peaks per stroke (C) and average pressure (D) plotted against the baseline condition as a function of age and constraints. Temp: temporal constraint; Space: spatial constraint; Temp–Space: spatio-temporal constraint. The bars indicate the standard deviations values. The value 1 indicates no change with respect to the Base condition.
4. Discussion

The main purpose of this study was to assess the impact of spatio-temporal constraints on handwriting movements for cursive letters among 5-, 6-, and 7-year-old children, but we first assessed how handwriting movement parameters changed from 5 to 7 years in a natural cursive letter copying condition. We will discuss the latter results before the former.

4.1. Early changes in cursive handwriting movements

Previous studies focusing on the development of handwriting movements in children were based on an older population than the one observed here, and to our knowledge, the present study is the first to report on kinematical handwriting movements for cursive letters in children who had not been introduced to learning handwriting. Our results are, however, consistent with those of Zesiger, Mounoud, and Hauert (1993), which indicated that the improvement in handwriting movements, between 8 and 12 years of age, was shown by a decrease in movement duration and trajectory length and also by an increase in velocity and fluency. We indeed observed, between 5 and 7 years of age, a decrease in the weighted mean number of velocity peaks and an increase in velocity, providing support to Hypothesis 1. Handwriting movements became more fluent and faster with age. In addition, the trajectory lengths were seen to decrease between 5 and 6 years of age, followed by a tendency to stabilise between 6 and 7 years of age. Finally, pressure remained unchanged between 5 and 6 years, and then increased between 6 and 7 years of age. This latter result contrasts with the earlier observations, which showed a decline in this index with age (Zesiger, 1995). However, an increase in pressure between 8 years of age and adulthood has already been reported (Chartrel & Vinter, 2006). It is likely that this parameter is much more sensitive to the experimental conditions than the other parameters, and that this sensitivity accounts, at least in part, for the inconsistencies noticed between the results (Kao, Shek, & Lee, 1983).

Unlike Meulenbroek and Van Galen (1986, 1988, 1989), whose studies highlighted a profile of discontinuous development in handwriting performance, our study revealed an overall monotonic development. It should be noted, however, that these investigations did not study the same age groups. From this point of view, our results were more in line with those of Mojet (1991) and of Zesiger et al. (1993). The changes observed within the movement parameters are traditionally explained by a switch from a mode of retroactive control to one of proactive control. At the start of the learning process, the children do not yet possess accurate perceptive and motor representations for the letters to be produced and thus are heavily reliant on information coming from sensory feedback. Learning to write leads to the formation of motor programs that allow children to free themselves from these feedbacks. The movement thus increases in velocity and fluency.

However, the increase in pressure with age we observed can qualify this statement. An argument could be that there is a change in the type of sensory feedback children use to perform the handwriting task, favouring, over time, information that allows optimal performance (Tremblay & Proteau, 1998). In this way, learning to write changes from a visual control towards a proprioceptive control of movements (Fischman & Schneider, 1985). In addition, at the beginning of the learning process, young children essentially use their proximal articulations and as a result, they make impulsive and large-sized movements. Motor maturity enables the distalisation of the movement, which gives children better control of their movements and, therefore, improves the precision of these movements.

Note, however, that the main part of these results has been collected with copying tasks. Differences may appear if children were required to produce letters or words under dictation, as shown by Rosenblum, Weiss, and Parush (2004) in an experiment comparing children who were proficient or nonproficient in handwriting. This body of research on dysgraphic children has also revealed that the analysis of handwriting movements should not only be limited to “on paper” movements, but also include “in-air” movements, that is, movements produced above the surface, between segments of compound letters, between letters or between words. These “in-air” movements consistently differentiated proficient and nonproficient children (Rosenblum, Dvorkin, & Weiss, 2006; Rosenblum, Parush, & Weiss, 2003).

4.2. Impact of spatio-temporal constraints on handwriting movements

In order to achieve our main goal, we presented 5-, 6-, and 7-year-old children with writing conditions that included temporal, spatial or spatio-temporal constraints. The results obtained showed that the different constraints induced modifications in the handwriting movements that were more marked in younger than older children, thus validating...
Hypothesis 2. In their study on the impact of spatio-temporal constraints on the production of repetitive graphic patterns, Meulenbroek and Van Galen (1986) did not observe any differences between 7 and 9 years of age. Our study showed that differences do decline with age, since they were greater between 5 and 6 years of age than between 6 and 7 years.

At all ages, the temporal constraint led to a decrease in the number of velocity peaks together with the requested increase in velocity. The young children therefore had the ability to increase their spontaneous writing speed and the temporal constraint allowed more fluent handwriting movements to be achieved, as expected in Hypothesis 3. The same effect was induced by the spatio-temporal constraint at the age of 6 and 7 years, but not at 5 years. This contrasting result may help us to shed some light on the role of a temporal constraint at 5 years. Five-year-olds tend to make ballistic movements under proactive control (Hay, 1978, 1979, 1984), which are not suited to producing complex patterns such as cursive letters. Moreover, as Van Mier (2006) showed, children of 4–5 years of age made discontinuous movements (zigzags) and continuous movements (waves) in a discrete way, producing short movements separated by pauses. Therefore, when learning new morphokineses, these young children are forced to adopt a strong retroactive control, which reduces their speed of execution. The instruction to increase velocity probably forced children to reduce their visual control and allowed them to program longer movements, which resulted in improved fluency. The addition of a spatial constraint probably limited the reduction of feedback control due to the temporal constraint. At the age of 6 and 7 years, thanks to children’s better knowledge of the letters’ shape and to the fact that they naturally write in smaller size, the addition of a spatial constraint to the temporal one did not modify the positive effect of requiring a higher speed on movement fluency.

Among the 5-year-old children, the spatial constraint (alone or together with the temporal one) resulted in a large decrease in the trajectory length, indicating that the spontaneous handwriting size at this age was much larger than that imposed by the task. In contrast, the length was relatively stable at 6 and 7 years of age, with the size of the spontaneous productions being smaller but closer to that required under the spatial constraint condition. This could be explained by the practice effects due to schooling and also by concurrent motor maturity. Among those young children who had only a small amount of experience in writing cursive letters, the writing lines defined spatial references that enabled the movement to be better organised. This decreased the distance covered, with the child adopting a more appropriate trajectory. The spatial constraint condition led also to a reduction in the writing velocity, greater at age 5 years than at older ages, certainly linked to the decreased trajectory length and thus in agreement with the isochrony principle (Vinter & Mounoud, 1991). A small decrease in the number of velocity peaks also appeared at 5 years, as at 7 years of age, following the spatial constraints. As suggested by Meulenbroek and Van Galen (1986), the lines may define spatial references that allow more precise programming of the movement, thus reducing the number of velocity peaks.

In conclusion, our study reveals that issuing instructions to increase speed and to write between lines benefited children learning to write, especially at the beginning of the learning process. The combination of both constraints may be a means of eliciting implicit learning processes that would facilitate the formation of associations between the different segments of a letter. The efficacy of these processes has been revealed in several studies, in typically developing children (Vinter & Perruchet, 1999, 2000, 2002) as well as in disabled children (Vinter & Detable, 2003). Our results suggest the importance of encouraging the production of a continuous movement, not hampered by continually referring back to the model. The instruction to increase speed achieves this aim, enabling the children to free themselves from the model.

However, this finding must be seen with caution, because, depending on their level of motor maturity, not all children can achieve good performance in this way. The importance of individual differences in handwriting performance, and particularly of gender differences, has been recently emphasized (Vlachos & Bonoti, 2006). It must be remembered that letters a, b, d, g, h, k, and q were removed from the analysis, and 15% of the remaining data were eliminated, mainly because of large deformations of letter shape under a time constraint. The speed instruction should not be used with difficult letters, and it should be combined with the spatial constraint in order to prevent too drastic an increase in the velocity. Its role should not be to achieve faster handwriting, a goal which concerns children older than those studied here, but to help young children to reduce the number of times they look at the model when they produce a letter. Bezruzhik (2005) reported that requiring accelerated handwriting is one important cause of difficulties in handwriting acquisition. Our recommendations do not contradict his position, since the positive impact of a temporal constraint on young children’s handwriting movements can only be seen when the velocity increase is moderate, rather than excessive. Finally, it would also be worth investigating the benefit of stressing movement fluency on young children’s
handwriting movements instead of movement velocity, because it has been shown that this leads to velocity improvement without diminishing writing accuracy (Søvik & Teulings, 1983). However, to our knowledge, such a study has not been carried out with young children.

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References


