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Improvement of handwriting automaticity among children treated for graphomotor difficulties over a period of six months

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ABSTRACT

Although fluency and automaticity of handwriting have been recognized as important research topics for 30 years, empirical data on respective developmental courses among typically developing children as well as clinical samples have remained very limited. To fill this gap, this study investigates the development of handwriting automaticity employing a longitudinal design, including monthly measurements over a period of six months for 48 kindergarten and school-aged children (first and second grades) in Switzerland attending school-based graphomotor therapy for handwriting difficulties. Handwriting automaticity is operationalized as the number of inversions of velocity measured during the completion of specific tasks on a graphics tablet. The results reveal different improvement patterns over time depending on the tasks to be completed. The clinical implications of the results are discussed.

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Handwriting; automaticity; graphomotor therapy; digitizer

Introduction

Handwriting is a cultural asset and part of every primary-school curriculum around the world. Contemporary scientific models conceptualize handwriting as a complex neuromotor skill simultaneously involving cognitive and motor processes that are controlled by a hierarchic architecture of both central and peripheral processes (Kandel, Peereman, & Ghimenton, 2013). Most scholars assume that these processes are at least partially executed synchronically in a parallel mode (e.g., Kandel, Peereman, Grosjacques, & Fayol, 2011; Van Galen, 1991; Van Galen, Meulenbroek, & Hylkema, 1986). Several studies have demonstrated interferences between central processes and ongoing movement executions, demonstrating that handwriting functions in a cascading manner (Delattre, Bonin, & Barry, 2006; Fayol & Lété, 2012; Kandel et al., 2013; Olive, Alves, & Castro, 2009; Olive & Kellogg, 2002; Roux, McKeff, Grosjacques, Afonso, & Kandel, 2013).

In addition to the central-peripheral distinction, writing is (in general) conceptualized as composed of both higher and lower order processes (Hayes, 2012a, 2012b). The former includes preceding cognitive processes (e.g., ideation or semantic coding such as the translation of meaning into words) while the latter refers to transcription, including retrieval of orthographic (spelling) and allographic (addressing the concrete realization of a specific grapheme) representations, activation of neuromuscular networks, and execution of fine motor movements.

Recently, Kandel and Perret (2015) have demonstrated that some lower order processes interact with each other and showed that orthographic irregularities already affect

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handwriting fluency among young children during the acquisition of handwriting. As the focus of this study lies on handwriting, lower order processes of writing are of special interest.

Developmental studies have revealed that preschoolers practice visual motor coordination and fine control of finger movements by drawing, long before handwriting acquisition in school starts. This progress in drawing is associated with handwriting since preschoolers with advanced drawing skills produce readable letters earlier compared to peers with poorer drawing skills (Levin & Bus, 2003). Learning to write by hand requires learning the allographs of the respective language and the corresponding phoneme sounds as well as the hand and finger movements required to execute the allographs. Further steps include the acquisition of spelling and orthographic coding as well as the execution of handwriting movements increasingly automatedly, fluently, and efficiently (Bosga-Stork, Bosga, & Meulenbroek, 2011; Abbott, Berninger, & Fayol, 2010; Bosga-Stork, Bosga, & Meulenbroek, 2014).

While handwriting acquisition quickly moves forward during first grade, handwriting development slows over the subsequent years of primary school (Karlsdottir & Stefansson, 2003; Mojet, 1991; Zesiger, Mounoud, & Hauert, 1993). Writing speed increases from about 20 letters per minute in first grade to approximately 110 letters per minute in ninth grade (ninth grade, Graham, Berninger, Weintraub, & Schafer, 1998). However, in addition to speed, other factors have been observed in children. An analysis of the upstrokes and downstrokes recorded by means of a digitizing graphics tablet reveals many more inversions of velocity within each stroke for children compared with adults (Meulenbroek & Van Galen, 1988). In other words, children's movements consist of multiple motor impulses within strokes, which causes measured changes in velocity ("dysfluency"). Advanced fluency in terms of both increased stroke frequency and automaticity (i.e., decreased number of inversions of velocity, NIV) has been proven as an important precondition of speed among third and fourth graders (Wicki, Hurschler Lichtsteiner, Saxer Geiger, & Müller, 2014). However, fluency determined by the mentioned factors is not yet perfect for most fourth graders Wicki et al. (2014).

According to Van Galen and Weber (1998), an adult's handwriting consists of highly adaptively programmed (and therefore learned) movement sequences. Meulenbroek and Van Galen (1988) summarized the results of several studies on the development of skilled handwriting they had completed. They recorded kinematic variables from young children (in first through sixth grades) who were asked to write repetitive patterns or letters on a digitizer and they compared these data with respective data collected from adults. Remarkably, their (cross-sectional) studies showed continuous decreases of dysfluency (i.e., increases of fluency) from grades three through six.

These innovative developmental studies have conceptually linked fluency/dysfluency and automaticity of handwriting to this "kinematic" approach used to measure the NIV (e.g., Chang & Yu, 2005; Marquardt, Gentz, & Mai, 1996; Rosenblum, Weiss, & Parush, 2003). While a young child's execution of an unknown pattern is likely to be visually controlled and slow (i.e., the child is looking at what he or she draws or writes and correcting his or her movements accordingly), this is not the case regarding well-known patterns, allographs, and words, which are expected to be executed by a much more automated process among older children and adults (Fitzpatrick, Vander Hart, & Cortesa, 2013; Khalid, Yunus, & Adnan, 2010; Quenzel & Mai, 2000; Rosenblum et al., 2003). Automated handwriting consists of fast, ballistic movements that are composed of a single acceleration followed by a deceleration per stroke (i.e., one inversion of velocity per stroke) (Mai & Marquardt, 1999).

Accordingly, a person fluently writing by hand generally requires only one velocity change per stroke (acceleration followed by deceleration), resulting in an NIV score of approximately 1 or exactly equal to 1, whereby 1 indicates perfect automaticity. Typically developing children, however, fall short of this level: When completing a sentence copying task, the mean NIV of typically developing fourth graders is around 2.7; however, when asked to rewrite the same sentence faster, these children were able to achieve a mean NIV of 1.6 (Hurschler, Saxer, & Wicki, 2010), which is just slightly worse than the mean value of 1.4 among adults when writing a sentence (Mergl, Tigges, Schroter, Moller, & Hegerl, 1999).

Studies investigating process characteristics of poor handwriting among clinical samples attending graphomotor therapy (i.e., children with dyslexia and children diagnosed with developmental coordination disorders, DCDs) are rare, and their results are mixed. Children with DCDs were found in some studies to handwrite at a much slower pace (Rosenblum, Aassy Margieh, & Engel-Yeger, 2013; Rosenblum & Livneh-Zirinski, 2008) and less fluently (Jolly & Gentaz, 2014) than typically developing peers. In contrast, Sumner, Connelly, and Barnett (2013) demonstrated that children with dyslexia are not slower writers compared with matched typically developing children but do pause more often due to a lack of orthographic skills. Similar findings were reported by Prunty, Barnett, Wilmut, and Plumb (2013) with respect to the handwriting speed of children with DCDs. However, the majority of studies did not measure automaticity as defined above (they mostly measured execution speed (cm/s)), and the referred diagnoses differed by study. Therefore, to further promote understanding of the respective processes of impaired handwriting, additional research is required.

To the best of our knowledge, occupational therapists' assessments for children referred with handwriting difficulties do not currently include digitizing tablets as a rule. However, developmental scales measuring visual motor skills (Beery & Beery, 2006), motor proficiency (Bruininks & Bruininks, 2005) and perceptual skills (Büttner, Dacheneder, Schneider, & Weyer, 2008; Gardner, 1982) are often included (Feder, Majnemer, & Synnes, 2000). This is mirrored in research as studies on the effects on school-based occupational therapy only rarely include process measures such as fluency, although some evaluation has been conducted using the mentioned standardized tests (e.g., Case-Smith, 2002).

The present study explores the course pattern over a period of six months of automaticity among young children with graphomotor difficulties that were referred to graphomotor therapy when handwriting four different patterns: garlands, arcades, double loops, and the (German) word "ein". Garlands and arcades are frequent elements of cursive handwriting; for example, the word "time" consists of two garlands followed by two arcades and a loop. Thus, fluency among such components is assumed to indicate improvement in handwriting skills (Rosenblum et al., 2003).

The longitudinal design of the present study enables a closer look at the course of automaticity, which is considered an important indicator of the development of handwriting. This has not yet been studied or documented longitudinally in a treated sample of children with poor handwriting.

Method

Study design

In Switzerland, only specialized professionals called psycho-motor therapists are authorized to practice school-based therapy to treat children with handwriting difficulties. The original sample of the study consisted of 60 Swiss pupils attending school-based psycho-motor therapy which is common as therapy similar to occupational therapy as reported in the introduction. These children were distributed over 12 psychomotor therapists who collaborated with the research team. We dropped the oldest children (those in third or a higher grade (n = 12)) to create a more homogenous sample in terms of age. Thus, we created a convenience sample of kindergarten, first or second grade students attending therapy with one of the collaborating therapists (N = 48). Students included in the sample attended school-based psycho-motor therapy over six months, and their handwriting was examined on a digitizing tablet using an extended version of the CSWin software (Mai & Marquardt, 1996) six times during the study period (at intervals of four to six weeks).

Participants

The selected sample (N = 48) comprised 39 boys and 9 girls, a ratio that is quite typical for students attending therapy for graphomotor difficulties. The youngest child was 67 months old, the oldest 123 months (M = 87 months). Boys and girls did not differ with respect to age.

Irrespective of gender, the children scored rather low on the fine motor skills subtest of the M-ABC-2 (Petermann, 2009) (M = 36%), indicating somewhat reduced fine motor skills. Table 1 presents a more detailed description of the sample.

The medical or psychological diagnoses of the participating children comprised language acquisition disorder (n = 9), attention deficit and hyperactivity disorder (n = 4), developmental disorder of motor functions (n = 2), tremors (n = 1), and cognitive delay (n = 1). However, the majority of the sample was referred by teachers without being diagnosed explicitly, which is a common situation in Switzerland.

Active consent to participate was received from all parents in advance.

Table 1. Description of the sample.

Variables	Kindergarten n (row %)	First grade n (row %)	Second grade n (row %)	Total
Gender				
(1) Boys	9 (23)	19 (49)	11 (28)	39
(2) Girls	1 (21)	4 (48)	4 (31)	9
Handedness				
(3) Right	2 (50)	1 (25)	1 (25)	4
(4) Left	8 (18)	22 (50)	14 (32)	44
Referral with med. or psych. diagnosis				
(5) No	9 (29)	14 (45)	8 (26)	31
(6) Yes (any)	1 (6)	9 (53)	7 (41)	17
Hand-motor coordination disorder				
(7) No	4 (33)	5 (42)	3 (25)	12
(8) Yes	6 (17)	18 (50)	12 (33)	36

Provided school-based handwriting interventions

The participating 12 psycho-motor therapists provided a variety of individualized interventions depending on the specific problems of a child once a week for 45–50 min. The children were treated in individually or in pairs by the same therapist for the duration of the study. However, they were unevenly distributed over the therapists (with a range of two to seven students for each therapist) due to the selection of younger children as described above. The interventions mainly included handwriting practice and sensorimotor, perceptual-motor, and motor learning, among other approaches (e.g., building motivation). In sum, the provided interventions are in line with recent conclusions about effective handwriting interventions (Hoy, Egan, & Feder, 2011).

Instruments and measures

Personal details of the participants and reasons for referral

Details on the children's history of graphomotor difficulties, handedness, gender, age, and reason for referral were collected by the participating therapists and submitted to the research team.

Movement ABC-2 and Developmental Test of Visual Perception (DTVP-2)

For a standardized measure of fine motor skills, the German version of the Movement ABC-2 subtest for fine motor skills (Petermann, 2009) was used. In addition, we applied the German version of the Developmental Test of Visual Perception (DTVP-2) (Büttner et al., 2008). Both tests were individually administered during the first treatment session by the participating therapists according to the respective user manuals.

Automaticity of handwriting

The handwriting tasks completed on the tablet refer to different developmental stages of handwriting. The battery used in a previous study Wicki et al. (2014) was supplemented by additional tasks and comprised a total of 25 tasks, beginning with up and down strokes in different directions, coils, triangles, and circles, continuing with garlands, arcades, double loops, syllables, words, and ending with the task of writing a dictated sentence. Many children could not complete all 25 handwriting tasks due to their age and/or difficulties. For the purpose of this paper, we analyzed the NIV of four tasks situated in the middle of the battery: garlands, arcades, double loops and the word "ein" (which is at once a syllable, a morpheme and a word in German). Figure 1 depicts the performance of these tasks by one of the participating children.

The four tasks were completed by almost all children in the sample from the beginning of the six measurements. Each child was expected to write each task three times in succession on the digitizer (e.g., double loops as ee ee ee). As outlined above, NIV indicates the average number of velocity changes while writing single strokes (within letters) (Mai & Marquardt, 1999).

Apparatus (digitizing tablet)

Handwriting movements were recorded and analyzed by means of the general software package CSWin (Marquardt & Mai, 2007) on therapists' notebook computers, which were

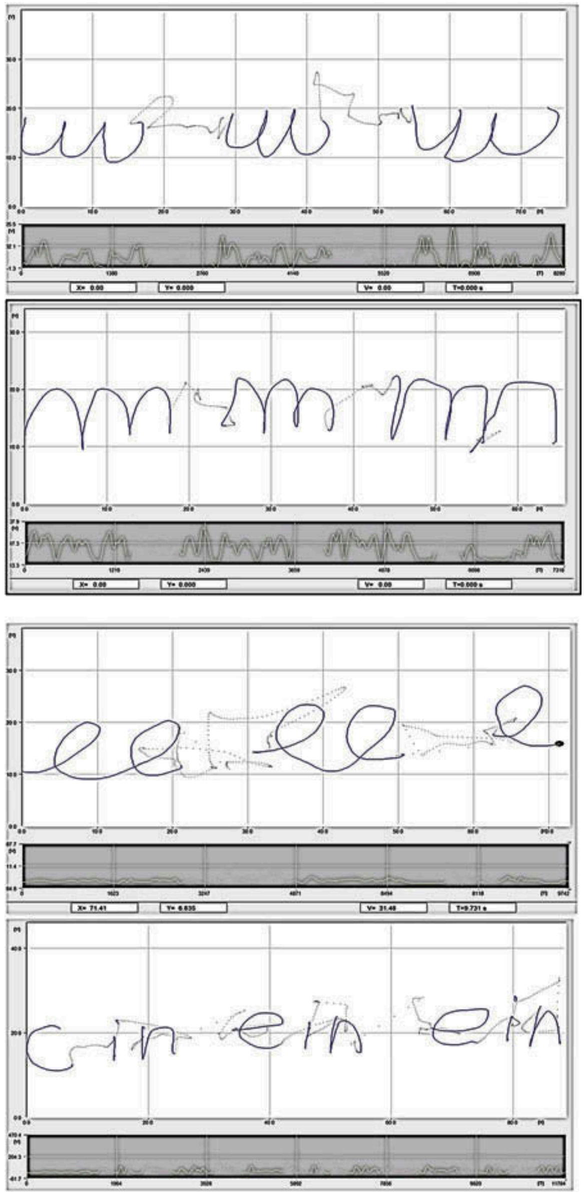

Figure 1. Handwriting tasks.

Note: The writing of garlands, arcades, double loops, and the word/syllable level (from top to bottom) from one child on the digitizer is represented. In addition, the respective velocity profiles are depicted.

connected to a digitizing tablet (Wacom Intuos 4 Pen Model PTK-640 and Intuos Inking Pen). The sampling frequency was 200 Hz, and the accuracy was 0.1 mm in both the x and y directions. Position data can be recorded even if the stylus is lifted (<10.0 mm) above the tablet due to the inductive method of measurement. Nonparametric regression methods (kernel estimation) are part of the mathematical procedures of the program (Marquardt & Mai, 1994) to calculate and smooth velocity and acceleration signals.

Procedure

All assessments were administered by the 12 participating therapists in the context of ongoing graphomotor therapy. The number of children assigned to each therapist varied between two and seven. Six measurements were taken for each child at monthly intervals. Before the study, the therapists attended training in how to administer data assessment on the digitizer provided by a staff member (i.e., the second author).

Data analysis

For the first step, we calculated nonparametric correlations between the two traditional diagnostic tools used in this study (M-ABC-2 and the DPVT-2) and our kinematic measures to explore the respective associations. Subsequently, since the NIV is skewed and not normally distributed (as confirmed by the Shapiro–Wilk test), we calculated the logarithmic (base 10) value of the measured NIV to meet the requirements for parametric statistics. These transformations worked well (all Shapiro–Wilk results were >.95 and n.s.). The log transformed values were used for longitudinal and cross-sectional analyses of automation as described in the following.

To analyze repeated measurements, we applied the linear mixed-effects models (MIXED) of the SPSS because these handle correlated data, which are very common in experimental subjects. After comparing several covariance models, we selected the compound symmetry covariance type as its very low −2 log likelihood values indicate it is the model that best fits the data. The compound symmetry covariance type assumes constant variances at each time point and constant correlations between measurements.

Cross-sectional differences between the automaticity of specific movements were analyzed by means of dependent t-tests with a Bonferroni adjustment of the p-level.

Results

In this section, we first relate paper and pencil tests administered in this study to the kinematic measures to explore the respective associations. Subsequently, we report four separate analyses of the course pattern of the investigated movements over time. Finally, we compare the level of automaticity among the patterns at different points in time.

Associations between M-ABC-2, DPVT-2, and kinematic measures

The nonparametric correlations calculated between the M-ABC-2 and the kinematic measures at time 1 reveal that the automaticity of writing garlands and arcades is negatively related to the M-ABC-2 fine motor subscale, which indicates that low automaticity is related to poor M-ABC-2 performance on these subtests (Table 2). In contrast, the M-ABC-2 was found to not be significantly related to the automaticity of the remaining tasks (double loops and word level). With respect to the DPVT-2, we found only the motor reduced subscale to be related to automaticity of double loops while the remaining associations were weak and not significant (Table 2).

In sum, while we found some connections between kinematic measures and the paper and pencil tests, they are not consistent.

Table 2. Means, SD, and nonparametric correlations between variables at time 1.

			Correlations (Spearman's *r*)						
	M	SD	−1	−2	−3	−4	−5	−6	−7
−1 M-ABC-2, percentile rank	36	32	0.1						
−2 DTVP-2, VMI percentile rank	24	28	.54**	0.1					.
−3 DTVP −2, MR percentile rank	45	29	.30*	.49**	1				.
−4 NIV garlands, t1	5.7	4.3	−.41**	−0.24	−0.17	1			.
−5 NIV arcades, t1	4.7	3.3	−.43**	−0.22	−0.28	.72**	1		
−6 NIV double loops, t1	9.5	10.9	−0.21	−0.15	−.32*	.66**	.64**	1	
−7 NIV word level, t1	5.4	4.3	−0.13	−0.1	−0.12	.37*	.62**	0.29	1

Notes: * $p < .05$, ** $p < .01$; $38 \leq n \leq 47$; M-ABC-2 = Movement-Assessment Battery for Children-2, fine motor skills subscale; DTVP-2, VMI = Frostig Developmental Test of Visual Perception, visual motor integration subscale (German version); DTVP-2, MR = Frostig Developmental Test of Visual Perception, motor reduced subscale (German version); NIV = number of inversions of velocity of respective tasks (garlands, arcades, double loops and word level) untransformed values are depicted.

Course pattern over time

The application of the MIXED procedure as described above revealed significant improvements of automaticity over time with respect to double loops ($F_{(5,\ 92.5)} = 7.78$, $p < .001$) and handwriting the German word "ein" ($F_{(5,\ 130.1)} = 6.53$, $p < .001$. In contrast, the improvement we observed in garlands ($F_{(5,\ 107.1)} = 1.97$, $p = .09$) just reached the level of a statistical tendency, and the change in arcades was weak (and not significant) and only observable from the first to the third measurement, as depicted in Figure 2.

Differences across tasks

A closer inspection of Figure 2 suggests that double loops are less automated compared to the other movements (i.e., garlands, arcades, and the word ein). We tested this hypothesis by means of a series of dependent *t*-tests. According to a Bonferroni correction, the *p*-value was adjusted to .01 because of multiple testing. At t1, double loops were clearly less automated than arcades ($t(44) = 6.3$; $p < .001$), the word ein ($t(37) = 3.4$, $p = .002$), and garlands ($t(44) = 4.7$, $p < .001$). In addition, children wrote garlands slightly less automatedly than arcades ($t(44) = 2.6$, $p = .01$). The remaining movements did not differ from each other. At t2 and t3, the pattern of differences between the tasks remained stable with the exception that arcades, garlands and the word ein no longer differed from each other (partly due to the Bonferroni adjusted *p*-value). These movements converged to a rather stable level with an NIV of around 4 from t4 to t6. At time 4, arcades were again more automated than double loops ($t(45) = 3.6$, $p < .001$), which no longer differed from garlands and the word ein while at time 5, we found that the word ein was better automated than double loops ($t(45) = 2.9$, $p = .005$). Finally, t6 arcades and the word ein were better automated than the double loops ($t(47) = 2.6$, $p = .01$ and $t(47) = 2.8$, $p = .008$, respectively).

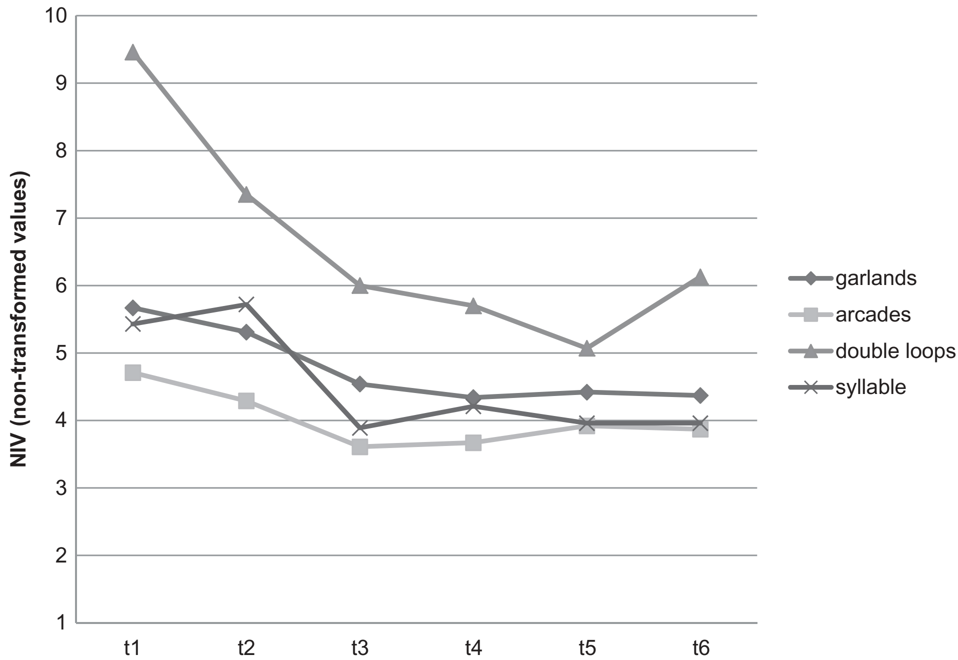

Figure 2. NIV change over 6 months (*t*1 – *t*6).
Note. Nontransformed NIV values are used.

Discussion

Inconsistent associations between paper and pencil tests and kinematic measures

The finding of inconsistent associations between the DTVP-2 and automaticity of handwriting is unsurprising since it parallels the very low correlations we found between automaticity of handwriting and another test of visual motor integration (VMI, Beery & Beery, 2006), which is more closely related to spelling than to motor activity Wicki et al. (2014). The moderate and inconsistent associations between automaticity and M-ABC-2 scores support our position that kinematic measures have an important diagnostic value that benefits adequate treatment of handwriting difficulties.

Improvement of automaticity

This study reveals poor automaticity of handwriting movements among young school children attending psycho-motor therapy, with steady improvement over time. The question of whether the observed improvement is attributable to mere developmental effects or are—at least partly—also the result of therapy remains unanswered since no control group is included in this study. Apart from this question, which was not the focus of this study, we are convinced that the longitudinal investigation and description of automation improvement has its own scientific practical relevance because automation is considered a core concept of handwriting according to the theoretical assumptions outlined in the introduction (cf. Marquardt et al., 1996). Moreover, the documentation of probable improvement in regards to well-defined movements such as garlands, arcades, words, and double loops over a specified period can increase our understanding of the respective learning processes in ongoing graphomotor therapy since such patterns are thought to constitute the basic elements of many if not almost all allographs in many scripts (e.g., English, French, Italian, Spanish, and German).

Different improvement patterns over time have been found and described depending on the completed task. Interestingly though, double loops were found to be less automated and improved to a lesser extent compared to other movements (i.e., garlands, words, and arcades). This finding is in line with Marquardt and Sattler (2010), who found relatively poor automation of double loops among typically developing children from the first to the fourth grade, despite clear improvement over the years. In the new semi-joined German script, double loops occur only as ee but are no longer taught as ll (i.e., double l). In consequence, respective syllables and words comprising this pattern occur comparatively seldom. Therefore, the finding could be explained simply by a lack of training of this movement compared with, for example, garlands or arcades.

Automaticity in clinical samples

Finally, the observed course of automaticity converged to a NIV level between 4 and 6, indicating a persistent lack of automaticity, even after attending graphomotor therapy over several months. Thus, it seems quite reasonable to also consider automaticity when discussing clinical samples such children suffering from DCDs (cf. Prunty, Barnett, Wilmut, & Plumb, 2016). However, since the present study lacks a control group, additional research including typically developing and clinical samples is necessary to determine the significance and impact of poor automaticity among children suffering from DCDs or other disorders that cause impaired handwriting. Moreover, additional longitudinal research on the course of automation in typically developing children is desirable to promote our understanding of their acquisition of fluent handwriting Wicki et al. (2014).

Clinical implications

Although reduced legibility among people with poor handwriting, caused by varying form and size of letters and space between them (e.g., Smits-Engelsman & Van Galen, 1997), is a serious problem, we argue that the development of automated handwriting movements is at least as important as legibility. Therefore, we recommend clinical assessments that—in addition to the traditional test batteries—include process measures utilizing digitizing tablets to continuously document the respective improvement. This may lead to a better fit while planning next steps of graphomotor training, because already well automatized movements can be used as baseline. Further on, improvement in fluency can be made visible to parents and teachers who tend to focus only on neatness. And, last but not least, the replay modus on the screen allows children to see their traces and improvements, and we know that experience of self-efficacy is an important condition of success.

Conclusions

From this study, it can be concluded that the automaticity of handwriting tasks such as garlands, arcades, double loops, and words improved over time and converged to some extent in a sample of children attending school-based occupational therapy. Longitudinal data on the automaticity of handwriting discerned new insights with respect to the general process underlying handwriting movements.

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