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Signal-to-Noise velocity peaks difference: A new method for evaluating the handwriting movement fluency in children with dysgraphia[☆]

Jérémy Danna [a,b,*], Vietminh Paz-Villagrán [a], Jean-Luc Velay [a]

[a] Laboratoire de Neurosciences Cognitives, UMR 7291, CNRS – Aix-Marseille Université, France
[b] Brain and Language Research Institute, LPL, CNRS – Aix-Marseille Université, France

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ABSTRACT

This study evaluated handwriting movement dysfluency related to dysgraphia. A new variable, the Signal-to-Noise velocity peaks difference (SNvpd), was proposed to describe abnormal velocity fluctuations in cursive handwriting. This variable was compared to two variables most frequently used variables for assessing handwriting fluency. This comparison was carried out for three different groups, children with dysgraphia, proficient children, and adults, all of whom wrote the same single word. The adults were taken as the reference. Results revealed that, of the three variables studied, the SNvpd proved most efficient in discriminating children with dysgraphia, and that furthermore, it had the significant advantage of facilitating the localization of dysfluency peaks within a word. Our results also showed that the movement dysfluency of children with dysgraphia was specific to certain letters. In light of these results, we discuss the methodological and theoretical relevance of this new variable to the analysis of handwriting movement with the aim of characterizing dysgraphia.

Nearly a third of school-aged children fail to develop the efficient handwriting performance required to cope at school (Rosenblum, Weiss & Parush, 2003; Smits-Engelsman, Niemeijer, & van Galen, 2001). It is among this population that one finds children with dysgraphia. Here we adopt the traditional definition of dysgraphia, which describes it as a disturbance or difficulty in the production of written language that is related to the mechanics of writing and the result of a failure to acquire the fine motor task of handwriting (Hamstra-Bletz & Blöte, 1993; Smits-Engelsman & van Galen, 1997).

In most European countries, the diagnosis of dysgraphia is usually based on the Concise Evaluation Scale for Children's Handwriting (Brave Handwriting Kinder – BHK, Hamstra-Bletz, de Bie, & den Brinker, 1987). In this test two criteria of cursive handwriting are analyzed: the quality of the written trace and the speed of production. The quality of the produced trace refers to the legibility of letters and words, i.e., their conformity with the norm. The speed of production denotes the writer's ability to write without loss of time and to do so with ease. When the handwriting movement and trace of children with dysgraphia are scrutinized, it can be observed that, while most of them produce illegible handwriting, some succeed in

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* Corresponding author at: Laboratoire de Neurosciences Cognitives, Pôle 3C, Case C, 3 Place Victor Hugo, 13331 Marseille Cedex 03, France. Tel.: +334 13 55 11 68.

E-mail addresses: jeremy.danna@univ-amu.fr (J. Danna), vietminh.paz@univ-amu.fr (V. Paz-Villagrán), jean-luc.velay@univ-amu.fr (J.-L. Velay).

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writing fairly correctly but with movements that lack fluency and efficiency. Such children are not easy to diagnose given that the most common complaint made about children with dysgraphic handwriting regards the quality of their script (Smits-Engelsman & van Galen, 1997).

More recent clinical tests, such as the Evaluation Tool of Children's Handwriting (ETCH-C, Amundson, 1995) or the Hebrew Handwriting Evaluation (HHE, Erez & Parush, 1999), take into account another criterion based on the observation of the handwriting production. For example, in the ETCH-C, bio-mechanical aspects of handwriting are determined by observing pencil grasp, pencil pressure, and in-hand manipulation. In the HHE, ergonomic factors are determined by analyzing pencil position, paper position, body posture, body stabilization, and fatigue. However, determining most of these criteria involves subjective visual evaluation. Objective and reliable measures of the real efficiency of handwriting movements are, strictly speaking, still lacking.

Thanks to the development of new tools (e.g. graphic or digitalized tablets) and appropriate software, several 'hidden' variables of the handwriting process have now been made available, permitting a more complete characterization of handwriting performance. Studying the temporal, kinematic, and dynamic aspects of handwriting movements allows us to better characterize the handwriting difficulties of children with dysgraphia (Rosenblum et al., 2003). But, given all these variables, how can we know which one will offer the best characterization of dysgraphia? In the following two tables we report the variables used in 42 studies analyzing a range of very different movement disorders, 12 of which focused on dysgraphia. The aim of these two tables is to determine those variables most frequently investigated in studies aiming to characterize graphic movement disorders, and, on that basis, to establish the distinguishing feature of dysgraphia.

The variables are organized into three categories corresponding to the temporal, kinematic, and dynamical content of the handwriting movement. Temporal variables inform us about the duration of performance. Kinematic variables correspond, here, to variations in the first derivative (the velocity), or the second derivative (the acceleration) of the pen position as a function of time. Finally, the dynamic variables result from an analysis of the forces generating the handwriting movements. Because we focus on the handwriting movement, spatial variables are not reported. Concerning kinematic variables, we distinguish two categories of handwriting movement analysis: a first that informs us about speed, and a second that informs us about fluency (smoothness). In each category, the variables are arranged with respect to their occurrence in all studies (right column). In certain cases, several variables were analyzed in the same study with the result that the sum of all cited variables exceeds the number of reported studies. For the sake of clarity, the reported studies are referenced in Table 2.

As can be seen in Table 1, the temporal variables concern, mainly, the Movement Time (MT) at two time scales, global (total MT) or local (stroke duration), and the ratio between the 'In Air' time and the 'On paper' time. Regarding kinematics and making a distinction between speed and fluency variables, it can be observed that speed is usually evaluated using the mean or the maximum velocity, and that fluency is determined by analyzing the supernumerary fluctuations in the velocity profile. The supernumerary velocity fluctuations correspond to additional accelerations and/or decelerations of the pen that are caused by a lack of control. These fluctuations are generally quantified by summing the number of velocity peaks or the number of inversions of the velocity (the former being twice the latter). In some studies, while the underlying aim remained the same, the supplementary abnormal fluctuations of the first or the second derivatives of velocity (the acceleration or the jerk) were also considered. Finally, concerning the dynamic variables, the mean pen pressure was analyzed most frequently. Significant pressure differences were only apparent in patients suffering from Writer's Cramp (e.g. Baur et al., 2006), they did not arise in children with dysgraphia (Khalid, Yunus, & Adnan, 2010; Kushki, Schwellnus, Ilyias, & Chau, 2011). Two limits of the pressure quantification should be pointed out: Firstly, pressure depends heavily on the tilt of the stylus with respect to the writing surface. Secondly, with standard graphic tablets (Wacom Intuos, for example), the reported pressure depends on the stylus used (the same stylus model does not always yield the same pressure values). Each stylus should, thus, be calibrated to establish the exact correspondence between the real pressure (i.e., in g/cm^2) and the values supplied by the stylus/tablet. For both of these reasons, between-study comparisons of pressure should be made with caution.

On the basis of all these studies, it appears that the most noticeable difference between children with and without dysgraphia is the very long total movement time involved in producing sentences in the former group. This longer movement time cannot be systematically explained by a lower speed of production only (Feder, Majnemer & Synnes, 2000; Kushki et al., 2011; Paz-Villagrán, Danna, & Velay, submitted for publication); four other factors may also be involved: a tendency to write larger (Hamstra-Bletz & Blöte, 1993), a very long 'in-air' movement time (Rosenblum, Parush, and Weiss (2003b)), more movement stops on the paper (Paz-Villagrán et al., submitted for publication), and a dysfluency of handwriting movements (van Galen, Portier, Smits-Engelsman, & Shomaker, 1993). Note that, concerning this last point, differences in fluency between the two groups of children were not systematically observed (Rosenblum, Dvorkin, & Weiss, 2006).

The main drawback of all the variables used to evaluate handwriting movement fluency (for example the number of inversion of velocity – NIV, or the averaged normalized jerk – ANJ) is that they fail to differentiate clearly between normal speed fluctuations, resulting from changes in curvature of the trajectory (Lacquaniti, Terzuolo, & Viviani, 1983; Viviani & Terzuolo, 1982), and 'abnormal' speed fluctuations, which stem from 'neuromotor noise' and which give rise to irregularities in movement control (van Galen, Portier, Smits-Engelsman, & Shomaker, 1993). In order to differentiate abnormal and normal fluctuations in a velocity profile, Meulenbroek and van Galen (1986) suggested evaluating the "Signal-to-Noise