RESEARCH ARTICLE OPEN ACCESS

Pauses in the Dynamics of Handwriting Production: Evidence of Persistent Difficulties in French Students With Dyslexia

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Received: 9 October 2023 | **Revised:** 10 September 2024 | **Accepted:** 25 September 2024

We would like to acknowledge the ASLAN project (ANR-10-LABX-0081) of the Université de Lyon for its financial support within the French program 'Investments for the Future,' operated by the National Research Agency (ANR). We also thank the financial support device PEPS CNRS (Université de Lyon & CNRS) and the École Normale Supérieure de Lyon for its financial support within the 'Projets Émergents' program.

Keywords: cognitive processes | dyslexia | handwriting | online indicators | written text production

ABSTRACT

Despite the persistent difficulties of people with dyslexia concerning writing, few studies examine the impact of dyslexia on the dynamic aspects of written text production. Our objective is to examine the written productions of students with dyslexia ($N=21$), compared with matched control students ($N=22$), taking into consideration online indicators. They were asked to produce spontaneous narrative and expository texts. The written texts ($N=86$) were collected using the Eye and Pen software with digitising tablets. Results show significant differences between the two groups concerning bursts and some pause locations and durations. While previous works conclude that the spelling difficulties of university students do not impact the transcription process anymore, which means that they no longer have effects on the dynamics of writing, and thus on writing fluency, our study qualifies these conclusions. Indeed, our results show that students with dyslexia's word transcription is atypical and problematic in terms of online indicators: they display shorter bursts (number of units written without a pause) and make longer pauses, especially inside and before words and before punctuation signs. The way in which they allocate cognitive resources is still partially altered by cognitive obstacles; their transcription process is also slowed down and disorganises other high-level cognitive operations.

1 | Dyslexia and Writing Persistent Difficulties

International studies reveal that university students with dyslexia still have difficulties with reading: the documentation on this issue is extensive (see Rice 2004, for a review). Rice, among others, shows that students with dyslexia continue to have a lot of reading difficulties, which he links to phonological aspects. Another difficulty mentioned by students with dyslexia (among others, (Giménez et al. 2015); Mazur-Palandre and Chenu 2020, 2023; Mazur-Palandre, Abadie, and Bedoin 2016; Mortimore and Crozier 2006), and which is much less studied (Connelly et al. 2006), concerns writing, which is considered 'a much more difficult skill, as it involves production as well as processing of print' (Connelly et al. 2006, 176). Quantitative analyses on the impact of dyslexia on writing at university confirm these feelings. Indeed, some studies reveal that dyslexic students confuse certain monosyllabic words, like *which* versus *with* (Singleton 1999), omit words from sentences (Singleton 1999), or use unexpected or inappropriate vocabulary (Farmer et al. 2001; Raskind and Higgins 1995; Sterling et al. 1998; Singleton 1999). They also produce less polysyllabic words than control students (Farmer, Riddick, and Sterling 2002). Nevertheless, recent French studies qualify these results, as they conclude that students with dyslexia produce the same types of word as control students, regardless of spelling consistency or the number of letters or syllables in the words used (Mazur, Quignard, and Witko 2021). That being said, they make more spelling errors, which confirms the conclusions of studies in English (Farmer, Riddick, and Sterling 2002; Hatcher, Snowling and Griffiths 2002; Singleton 1999), Spanish (Giménez et al. 2015) or French (Mazur-Palandre 2018, 2019; Mazur, Quignard, and Witko 2021, 2022). Moreover, they display syntactic (Farmer, Riddick, and Sterling 2002; Mazur-Palandre 2018, 2019) and punctuation problems too (Mazur and Quignard 2023). Some researchers speak about a deficit in the identification of errors and their correction (Horowitz-Kraus and Breznitz 2011). Subjects with dyslexia do not automate spelling during childhood like typical subjects (Berninger and Swanson 1994).

Once spelling has been automated, more cognitive resources can be allocated to higher-level processes such as syntactic packaging or revision (Bereiter and Scardamalia 1987). In line with the capacity theory (McCutchen 1996), a lack of automation in spelling may have a negative impact on compositional performances (Fayol and Miret 2005). Most of the existing studies on writing focus on offline indicators, like lexical choices or spelling. But, we know, for instance, that dyslexia has an impact on the revision process of children and students with dyslexia: their revision system is less efficient than that of control students (Mazur-Palandre and Chenu 2020, 2023); Morken and Helland 2013; Sumner and Connelly 2020). In this paper, we propose to examine the written language production of students with dyslexia and control students matched in age, university level and gender by taking into consideration other online indicators because they make a significant contribution to our understanding of writing processes (Schilperoord 1996). We hypothesise that the lack of automation in spelling conversion impacts online indicators related to high-level writing processes.

2 | Written Production Activity

The activity of writing is a very costly and complex cognitive task, more than reading or playing chess (Kellogg 1996), which involves various cognitive processes (Hayes and Flower 1980; Hayes 1996, 1998; Kellogg 1996, 1998): planning ideas ('planification' for Hayes and Flower; 'formulation' for Kellogg); translating (or 'execution' for Kellogg, developing internal representations in linguistic and graphic structures); and reviewing (or 'monitoring' for Kellogg, performing control operations on the text). Planning and reviewing appear to be the costliest processes, planning because of information recuperation in long-term memory and reviewing because it involves several costly processes, among which an important part is devoted to the correction of spelling errors (Hayes 1996; Kellogg 1987; McCutchen, Francis, and Kerr 1997). Translating is the least expensive writing process (Kellogg 1996) for expert writers without written language disorders. This lower cost can be partly explained by the fact that this process involves mechanisms that have become automatic with age and experience in writing, such as the graphic execution of texts (Kellogg 1996, 1998). Moreover, the writing processing system is described as a capacity-limited system (see Authors 2023, for a more descriptive explanation): the more cognitive resources the individual allocates to transcription, the less will be available for other high-level processes like planning (McCutchen 1996). Writing also entails (Bonin and Fayol 1996; Foulin, Fayol, and Chanquoy 1988), (1) the treatment of several linguistic and conceptual dimensions during graphic production; (2) the cost of the transcription step, regardless of how small it is; and (3) the possible impact of the cognitive resources allocated to the low-level processes on high-level processes.

For typical subjects, the spelling process becomes automated with age and experience (Berninger and Swanson 1994), which allows for more resources to be allocated to higher-level processes, such as planning and reviewing. Among other things, this freeing up of resources enables writers to use a high-level planning strategy like knowledge transformation or knowledge crafting, rather than knowledge telling (Bereiter and Scardamalia 1987; Kellogg 2008). The development of these strategies is strongly linked to the automation of certain processes, in particular graphomotor gestures and the orthographic conversion system. Previous studies reveal that the quality and length of written texts depend on the automation of spelling conversion (Berninger and Swanson 1994), and the high cost of the spelling dimension is said to result in 'poor compositional performances' (Fayol and Miret 2005, 397). Indeed, in children with typical development, the phoneme/grapheme conversion system and graphomotor processes are automated approximately between 9 and 12 (Berninger and Swanson 1994), even though it is not before the age of 16 that adolescents can totally manage all aspects of written production, including the planning process (Piolat 2004). However, people with written language disorders, such as dyslexia, do not automate the spelling conversion system (Berninger and Swanson 1994). Differences in the management of the spelling conversion system affect certain online indicators of written production, like handwriting speed, which seems to have an impact on the amount of text produced, but also its quality (Alfonso et al. 2020, 1; Connelly et al. 2006; Connelly et al. 2012; Graham et al. 1997; Limpo, Alves and Connelly 2017; Puranik and Al Otaiba 2012). Dyslexic adolescents who have not automated spelling are very disadvantaged (Graham and Perin 2007; Graham 2006). During a writing activity, they have to carry out different operations (organising their ideas, translating them into words in accordance with the rules of the writing system), are faced with a number of constraints (types of text to produce, instructions, etc.) and so forth. They do not just have to quickly produce a legible graphomotor trace (Olive, Kellogg and Piolat 2002). Non-automated spelling conversion entails the mobilisation of cognitive resources to handle the process, and the direct consequence of this is that less cognitive resources are available for high-level processes. This can be observed with online indicators, for example, handwriting speed, which is impacted by this distribution of cognitive resources (Brown et al. 1988).

Moreover, after the age of 10, handwriting becomes an autonomous skill, independent of spelling abilities (Bosga-Stork et al. 2016; Palmis et al. 2017): from this age onwards, handwriting speed is no longer associated with the graphomotor aspects of written production, and we can observe online indicators assuming that there is no possible impact of graphomotor gestures. The study of online indicators, like handwriting speed, word rate, bursts or pauses, helps to explain the written processes and the difficulties of typical and atypical writers (Alamargot, Morin, and Simard-Dupuis 2014; Brun-Henin et al. 2012; Witko and Chenu 2019).

3 | Spelling Conversion in French

For the expert adult, the translating process is less costly than planning and reviewing (Kellogg 1996), due to an automation of the phoneme–grapheme and grapheme–phoneme conversion system. Conversion systems can be more or less transparent or opaque (Jaffré and Fayol 1997). Spelling consistency refers to the stability of correspondences between phonemes and graphemes. The transparency of a spelling system refers directly to the relationship between these 2 units (Bonin, Collay, and Fayol 2008). Transparent spelling conversion systems feature simple correspondences between the 2 units, while opaque systems feature numerous complex correspondences (Pacton, Fayol, and Perruchet 2002). French spelling is complex because of its opacity (Jaffré 2009), with over 130 graphemes and around 30 associated phonemes. In comparison, Italian and Spanish have almost as many graphemes as phonemes: their phoneme/grapheme and grapheme/phoneme conversion systems are much more stable and pose fewer problems for learners, whether or not they have written language difficulties. For instance, French has several graphemes for the phoneme [s]: S, SS, T, SC, Ç, X, Z and so forth, whereas in Spanish, the same phoneme is associated with a single grapheme, S. Another example is the phoneme [k] in French, which can be spelled C, QU, K, CK or CH (Fayol 2003). The international literature shows a detrimental effect of spelling inconsistency on spelling performance (Bonin, Collay, and Fayol 2008), whether in children or adults, and, as a consequence, its impact is greater on the reading and writing performances of individuals with written language disorders.

We can therefore assume that the translating process, which is so cognitively inexpensive in adult experts (Kellogg 1996), remains relatively costly for people with dyslexia, due to the lack of automation of the spelling conversion system. This then has a major impact on the other high-level processes involved in written production, that is, planning and reviewing. Online indicators studies analyse cognitive activities as they unfold and appear to be clues that can account for the activation of processes (Favart and Olive 2005), among them there are handwriting speed, word rate, bursts or pauses. These types of analyses allow for a step-by-step observation of the operations involved in the writing process and take their processing time into account, and therefore appear as good indicators of how they are treated.

4 | Impact of Dyslexia on the Dynamics of Handwriting

Among the different online indicators, we decided to focus on handwriting speed, word rate, bursts and the duration of pauses with respect to their location in the sentence.

Handwriting speed provides information about the writer's writing dynamics. It corresponds to the total distance of tracings divided by the writing time in cm/s, without taking into account pauses or movements in the air (Afonso et al. 2020; Brun-Henin et al. 2012; Witko and Chenu 2019). During the writing activity, changes in the handwriting speed may reflect planning or difficulties in elaborating one's text (Binet and Courtier 1893; Kellogg 1987; Foulin, Chanquoy, and Fayol 1989). There is no consensus concerning significant differences between subjects with or without dyslexia among studies on dyslexic children (Sumner, Connelly, and Barnett 2014) or dyslexic students (Sumner and Connelly 2020). Moreover, the studies that we found propose analyses with subjects of varied ages. Results of a study on children aged 9 years reveal that handwriting speed (in terms of the physical distance covered by the pen divided by the time spent writing) is the same for both children with and without dyslexia, and the slow writing of children with dyslexia is due to the production of pauses, which are longer and more frequent (Sumner, Connelly, and Barnett 2014). According to Sumner and Connelly (2020), there is no significant difference between dyslexic students and control students, either in terms of handwriting speed (same definition as Sumner, Connelly, and Barnett 2014) or pauses. However, a recent study on French dyslexic teenagers (Witko and Chenu 2019) reveals that their handwriting speeds are below those found for typical middle-schoolers of the same age (Mordelet 2013; Chenu et al. 2011) and are more in line with the handwriting speeds of 11-year-olds.

Word rate, defined as the number of linguistic units (words, letters, syllables) produced in a given period of time (minutes or seconds), is rarely observed in studies on online indicators (Bonin and Fayol 1996), but it can be impacted by the cost of the transcription as well as by a spelling conversion system that is not totally automated. Moreover, for adult writers, an increase in the cognitive load on the conceptual and linguistic levels can result in a slowdown of their word rate (Brown et al. 1988), which is also sensitive to the degree of accessibility of information in memory (Foulin, Fayol, and Chanquoy 1988). Familiarity with the theme of the text also plays a role: the more the theme is familiar, the faster the writing speed is (Brown et al. 1988; Kellogg 1987). Some studies include word rate to their indicators, like Sumner, Connelly, and Barnett (2014), who conclude that children with dyslexia (9-year-olds) wrote the same number of letters per minute in an alphabet task but fewer words per minute, compared with children without dyslexia. Similar results were found for students or adults with dyslexia, concluding that they produce fewer letters per minute (Connelly et al. 2006) or fewer words per minute in a sentence copying task (Hatcher, Snowling, and Griffiths 2002) than control students. That being said, a more recent study on students with dyslexia concludes that there are no significant differences between students with and without dyslexia concerning the total number of words written per minute (Sumner and Conelly 2020), in a text writing task (an essay).

Bursts are also an interesting indicator to observe the writing process and allow to describe and analyse cognitive operations (planning, transcription, etc.) (Witko and Chenu 2019). This unit is defined as the average length of text written between two long pauses[1] (Alves and Limpo 2015; Limpo and Alves 2017; Witko and Chenu 2019) and the idea is to see whether writers have the skills to produce a long series of words without long pauses. The length of bursts is said to reflect the quality of a text (Limpo and Alves 2017): the longer the writing time without pause, the more it reflects fluidity in written production (Alves and Limpo 2015; Limpo and Alves 2017;

Witko and Chenu 2019). Previous studies reveal a difference between teenagers (12-year-olds) with and without dyslexia: the written production of dyslexic adolescents is regularly suspended by long pauses (threshold at 2s), which is less the case for adolescents without dyslexia (Witko and Chenu 2019). The question is also to know, in the present paper, whether university students with dyslexia are able to have long moments of production without a long pause, or whether they rather have short moments interspersed with pauses of varying lengths (Alamargot, Morin, and Simard-Dupuis 2014).

In order to track the cognitive processes involved in writing as they unfold, we can use several online methods and techniques, that allow us to analyse the production of written texts in real time and to describe their temporal course and functional characteristics (Olive 2010, 2011), recording pause productions and execution periods being one of them. Thus, the study of pause production, due to its correlation with cognitive processes, appears indispensable to define the dynamics of writing (Ailhaud and Chenu 2018). Numerous studies have focused on the analysis of pause production and agree on defining it as a moment of pause in writing, a time of inactivity. We can study two characteristics of pauses: location and duration. For this paper, we focus on location, in relation to bursts. Duration has been studied in a previous paper (Mazur and Quignard, submitted). We can then observe pauses according to their linguistic location, following a hierarchy of linguistic units: pre-writing pause, inter-paragraph, inter-sentence, inter-clause, inter-word and intra-word (Chesnet and Alamargot 2005) and punctuation (Foulin 1998). There exists a link between location and duration: the longer the unit is, the longer the pause is (Ailhaud and Chenu 2018; Foulin, Chanquoy, and Fayol 1989; Immonen and Mäkisalo 2017; Witko and Chenu 2019), even if before certain unites like punctuation and connectors, pauses do have a longer duration because they involve important syntactic planning (Foulin, Chanquoy, and Fayol 1989). Moreover, the location and duration of pauses according to the boundaries of linguistic units may highlight some difficulties: long pauses between words could reveal a deficient spelling processing, while longer pauses at the boundaries between clauses or sentences would reveal a more or less efficient planning processing (Ailhaud, Chenu, and Jisa 2016; Witko and Chenu 2019). It seems that teenagers with dyslexia produce an atypical transcription of words in terms of online indicators during written production, with a slower handwriting speed, a smaller length of writing passages without pause, or with longer pauses between words and punctuation than typical teenagers (Sumner, Connelly, and Barnett 2014; Witko and Chenu 2019). Authors conclude that the allocation of cognitive resources is modified by cognitive hindrances and that the process of word transcription can slow down or disorganise other higher-level cognitive operations. These conclusions confirm those of Galbraith et al. (2012), who showed that students with dyslexia produce longer pauses within and between words than control students and concluded that persistent difficulties with low-level processes interfere with high-level processes. Nevertheless, some studies on the writing processes of students with dyslexia do not support this view, specifically concerning pause times (Sumner and Connelly 2020), suggesting that spelling difficulties do not hinder the transcription process (fluency of handwriting/writing) more (Sumner and Connelly 2020).

5 | Methods

5.1 | Participants

The data collection was carried out as part of projects concerned with the difficulties and needs of French students with dyslexia, which involved several steps: (1) two online questionnaires (Mazur and Quignard 2023); (2) a speech and neuropsychological assessment (Mazur-Palandre, Abadie, and Bedoin 2016); and (3) a psycholinguistic task (production of four oral and written texts). The present article focuses on written psycholinguistic data from dyslexic and control students, matched for gender, age and school level (Table 1).

The students with dyslexia were diagnosed during childhood, have associated dysorthographia and received speech therapy. The students were all monolingual native French speakers and had all attended school in France. They gave their written consent to participate in the study. Exclusion criteria excluded people with hearing or visual impairments or other disorders.

5.2 | Protocol

During the psycholinguistic task, the students were asked to produce a text in four experimental conditions (Berman and Verhoeven 2002): oral narrative, written narrative, oral expository and written expository. For the expository text, they were asked to produce a text on problems between people, discussing the theme and presenting their ideas as if it were a school presentation. For the narrative text, the participants were asked to tell a personal story about a conflict they had experienced. The data collection took place in two sessions, 1 week apart. In the first session, they watched a 3-minute wordless video depicting various short scenes of conflict between people in a school environment (Spencer project, R. Berman). They were then asked to produce a narrative or

TABLE 1 | Description of the subjects who participated in the psycholinguistic task (age in years).

	Students with dyslexia	Control students
Mean age	21.7	21.8
Standard deviation	2.8	2.9
Age (min–max)	18.1–28.5	18.1–28.9
Total number of participants	21	22
Gender	9 women/ 12 men	10 women/ 12 men
University level		
Bachelor	15	15
Master	4	5
PhD	1	1
Other	1	1

expository text, both written and oral. In the second session, the participants were asked to produce the other two texts. Between the productions of the written and oral texts, they completed a language questionnaire. The order of production was counterbalanced (See Mazur and Quignard 2023 or Mazur-Palandre and Chenu 2023 for further information on the methodology).

5.3 | Data

We asked the participants to write by hand with a pen and paper, as they usually do in an academic setting, with no specific instructions regarding spelling, proofreading, production time and so forth. The written data were collected using the Eye and Pen software (Chesnet and Alamargot 2005) and transcribed according to the CHILDES conventions, then exported into the CLAN software. The productions were divided into clauses (unit of meaning composed of a finite or non-finite verb and its arguments) and terminal units (TU, a unit composed of a main clause and all its dependent clauses such as its subordinates) (Berman 1998; Hunt 1970). The corpus of written texts includes 86 written texts (43 expository and 43 narrative texts). Table 2 gives some information on the length indicators of the written texts of the corpus (See Mazur and Quignard 2023 or Mazur-Palandre and Chenu 2023 for further information on data collection).

ANOVA analyses reveal that the differences in length between students with dyslexia and control students in terms of number of words ($F_{(1,39)} = 0.089$, $p = 0.767$), clauses ($F_{(1,39)} = 1.842$, $p = 0.183$), T Units ($F_{(1,39)} = 2.501$, $p = 0.122$) and clauses per T Unit ($F_{(1,39)} = 0.773$, $p = 0.385$) are not significant, just like the differences in time duration (duration of written production, $F_{(1,39)} = 2.07$; $p = 0.164 > 0.1$).

5.4 | Data Analysis

We decided to observe several indicators: handwriting speed, word rate, bursts and pause location.

We define handwriting speed as the average speed of pen movements on the tablet (cm per second). This indicator is provided by the Eye and Pen software and includes the cumulative length of all traces (in cm) divided by their cumulative duration (in seconds). This excludes every move when the pen is up or held down, and thus all pauses. This definition is in line with previous works (Afonso et al. 2020; Brun-Henin et al. 2012; Witko and Chenu 2019).

Word rate is defined as the number of words produced divided by the time duration between the first and the last writing movements. Word rate includes pauses. The measure that we use corresponds to the number of words per minute.

Burst is defined as the average number of words produced between long pauses (more than 2 s, Alves and Limpo 2015) and calculated as follows: the number of words produced in the written text divided by the number of long pauses during the production.

Finally, we analyse the duration of pauses with respect to their location in the sentence: pauses inside a sequence (defined by Chesnet and Alamargot (2005) as a set of consecutive events located in time and to which labels, descriptions and comments can be associated, either a word or a punctuation sign), before a sequence, pauses before words, before punctuation signs, before clauses and before new lines. Duration values are given in milliseconds (ms).

6 | Operational Hypotheses

Given previous evidence concerning online indicators during written production in adults, we predict that the students with dyslexia H1 have the same handwriting speed as the control students; H2—but do not have the same word rate; H3—can of course produce a series of words but shorter than the control students; and H4—finally, display the same pause durations as the control group regardless of their location.

7 | Statistical Analyses

Priority was given to analyses comparing the means of the two groups (ANOVA). When the validity conditions of the ANOVA were not met, we performed a Kruskal–Wallis test. These analyses are carried out between groups (students with dyslexia vs. control group) with the alpha level of 0.05. The effect size is called large when greater than 0.14, moderate when greater than 0.06 and low otherwise.

Outliers: Because our experimental protocol allows individuals as much time as they deem necessary to write their text,

TABLE 2 | Length indicators for the written texts according to the text type and group (with their standard deviations in brackets).

	Expository texts		Narrative texts	
	Dyslexic students	**Control students**	**Dyslexic students**	**Control students**
Mean duration of production (in minutes)	13,85 (8,60)	11,02 (8,16)	11,77 (7,60)	9,01 (4,94)
Number of words per text	198,2 (101)	181,1 (139)	207 (131)	181 (112)
Number of clauses per text	25,8 (12,7)	25 (17)	30,7 (20)	27 (16)
Number of TU per text	12 (5)	12 (9,4)	14,7 (9,9)	13,8 (8,2)
Number of TU per clause	2,1 (0,5)	2,2 (0,4)	2,1 (0,3)	2,04 (0,5)

there may be considerable variability between individuals and very long pauses. The literature highlights the effect of outliers[2] on analyses (Field 2013). Rather than removing them from the dataset, we made the methodological choice of neutralising them by replacing them with the individual's median value.

Texts: In addition, as mentioned in the methodology section, the task requires the students to write two texts: one narrative and one expository. The tests are performed on the average of each measure on the two texts.

Results tables: Tables show the numbers, means and standard deviations of the two populations, as well as the result of the statistical test (ANOVA or Kruskal–Wallis). If the test is significant, the effect size is provided.

8 | Results

8.1 | Handwriting Speed

Table 3 presents the average handwriting speed for the students with dyslexia and the control students, and the mean comparison tests (ANOVA) performed, which reveal that the average handwriting speeds are very similar in both groups.

8.2 | Word Rate

Table 4 presents the average number of words produced per minute for the students with dyslexia and the control students, and the mean comparison tests (ANOVA) performed.

8.3 | Bursts Length (In Words)

Table 5 presents the average length of bursts for the students with dyslexia and the control students, and the mean comparison tests (ANOVA) performed.

TABLE 3 | Average handwriting speed (measured in centimetres per second).

Group	*N*	Mean	SD	ANOVA
DYS	21	2.95	0.741	$F_{(1,41)} = 0.004$; $p = 0.948$
CTRL	22	2.97	0.549	

TABLE 4 | Word rate (calculated in words per minute).

Group	*N*	Mean	SD	ANOVA
DYS	21	17.4	4.27	$F_{(1,41)} = 3.156$; $p = 0.083$
CTRL	22	19.8	4.58	

Note: There is no significant difference concerning word rate between the two groups.

8.4 | Pause Duration According to Their Location

Table 6 presents the pause duration for the students with dyslexia and the control students, and the mean comparison tests (Kruskal–Wallis) performed.

8.4.1 | Inter-Sequence Pause Duration

Table 7 presents the inter-sequence pause duration for the students with dyslexia and the control students, and the mean comparison tests (ANOVA) performed.

8.4.2 | Intra-Sequence Pause Duration

Table 8 presents the intra-sequence pause duration for the students with dyslexia and the control students, and the mean comparison tests (ANOVA) performed.

8.4.3 | Pause Duration Before a Word

Table 9 presents the pause duration before a word for the students with dyslexia and the control students, and the mean comparison tests (ANOVA) performed.

TABLE 5 | Bursts length (in words).

Group	*N*	Mean	SD	ANOVA	Effect size
DYS	21	7.13	3.27	$F_{(1,41)} = 4.087$; $p = 0.05$	0.09
CTRL	22	9.51	4.35		

Note: The average length of bursts is significantly shorter for the students with dyslexia (7.13 words) than for the control group (9.51 words) with a moderate effect size.

TABLE 6 | Pause duration (in milliseconds).

Group	*N*	Mean	SD	Kruskal–wallis	Effect size
DYS	21	215	68.3	$H_{(1,43)} = 3.87$; $p = 0.049$	0.07
CTRL	22	176	56.9		

Note: Results reveal significant differences between the two groups: the students with dyslexia display a longer mean pause duration (215 ms) than control students (176 ms). The effect size is moderate.

TABLE 7 | Inter-sequence pause duration (in milliseconds).

Group	*N*	Mean	SD	ANOVA	Effect size
DYS	21	630	177	$F_{(1,41)} = 6.365$; $p < 0.016$	0.13
CTRL	22	494	175		

Note: Results show that the mean inter-sequence pause duration (pauses between words and punctuation signs) is significantly longer for the students with dyslexia (630 ms) than for the control students (494 ms). The effect size is moderate.

8.4.4 | Pause Duration Before a Punctuation Sign

Table 10 presents pause duration before a punctuation sign for the students with dyslexia and the control students, and the mean comparison tests (Kruskal–Wallis) performed.

8.4.5 | Pause Duration Before a New Line (At the End of the Line)

Table 11 presents pause duration before a new line for the students with dyslexia and the control students, and the mean comparison tests (Kruskal–Wallis) performed.

8.4.6 | Pause Duration Before a New Clause

Table 12 presents pause duration before a new clause for the students with dyslexia and the control students and the mean comparison tests (Kruskal–Wallis) performed.

To summarise, these results reveal some interesting differences, not in the writing speed itself, but as a consequence of pauses. Results show significant differences between the two groups in terms of bursts and pause duration. Indeed, students with dyslexia:

- display shorter bursts;
- make longer pauses in general;
- make longer pauses between and inside sequences, before and inside words, and before punctuation signs compared with control students.

TABLE 8 | Intra-sequence pause duration (in milliseconds).

Group	*N*	Mean	SD	ANOVA	Effect size
DYS	21	210	44.3	$F_{(1,41)} = 4.715$; $p = 0.036$	0.10
CTRL	22	179	47.5		

Note: The average intra-sequence pause duration (pauses inside (and mostly) words) is significantly longer for the students with dyslexia (210 ms) than for the control students (179 ms). The effect size is moderate.

TABLE 9 | Pause duration, when preceding a word (in milliseconds).

Group	*N*	Mean	SD	ANOVA	Effect size
DYS	21	610	166	$F_{(1,41)} = 4.528$; $p = 0.039$	0.10
CTRL	11	500	171		

Note: Results show that the students with dyslexia display a significantly longer pause duration before a word (610 ms) than the control students (500 ms). The effect size is moderate (0.10).

TABLE 10 | Pause duration, when preceding a punctuation sign (in milliseconds).

Group	*N*	Mean	SD	Kruskal–wallis	Effect size
DYS	21	1138	959	$H_{(1,43)} = 8.08$; $p = 0.004$	0.17
CTRL	22	493	416		

Note: Pauses preceding punctuation signs are statistically longer in the texts of the students with dyslexia (1138 ms) than in the texts of the control group (493 ms). The effect size is large.

TABLE 11 | Pause duration, when preceding a new line (in milliseconds).

Group	*N*	Mean	SD	Kruskal–wallis
DYS	21	1503	462	$H_{(1,43)} = 0.430$; $p = 0.512$
CTRL	22	1862	1693	

Note: There is no significant difference concerning pause duration before a new line between the two groups.

TABLE 12 | Pause duration, when preceding a new clause (in milliseconds).

Group	*N*	Mean	SD	Kruskal–wallis
DYS	21	2438	1283	$H_{(1,43)} = 0.852$; $p = 0.356$
CTRL	22	3028	4307	

Note: There is no significant difference concerning pause duration before a new clause between the two groups.

9 | Discussion

In our study, we decided to focus on four online measures: handwriting speed, word rate, bursts and the duration of pauses according to their location. Our results confirm some of the previous results, while also providing new insight on them. An interesting and innovative aspect of our study lies in the fact that we observe a previously understudied indicator (bursts), and pauses are observed more precisely, because we examine their location.

9.1 | Non-Significant Results

This study does not detect any significant differences between the two groups in terms of handwriting speed, word rate and for two pause duration indicators. Concerning handwriting speed, our results confirm those of Sumner and Connelly (2020): students with dyslexia have the same writing dynamic as control students and produce the same distance of tracings per writing time. Handwriting speed may reflect planning difficulties or difficulties in elaborating one's text (Binet and Courtier 1893; Kellogg 1987; Foulin, Chanquoy, and Fayol 1989). So, our study showing that students with dyslexia have a handwriting speed equivalent to that of control students supports evidence from previous observations and the conclusion that spelling conversion system difficulties do not hinder the transcription process (fluency of handwriting/writing) anymore (Sumner and Connelly 2020). Moreover, our analyses also reveal that students with dyslexia have a word rate equivalent to that of control students, with approximately the same number of words written per minute. This finding is contrary to previous studies that have suggested that participants with dyslexia do not have the same word rate than control participants. These studies have demonstrated that students or adults with dyslexia produce fewer letters per minute (Connelly et al. 2006; Hatcher, Snowling, and Griffiths 2002) than control groups. However, the difference in results may be due to a difference in task. Indeed, the students in our study had to produce a written text with all the complexity that this implies (planning, translating and revising). However, in the studies mentioned above, the task does not consist in writing a text in its entirety but in writing out the letters of the alphabet in lowercase and in order, as quickly as possible within 1 min (Connelly et al. 2006) or to copy out a sentence as many times as they can in 2 min (Hatcher, Snowling, and Griffiths 2002). This explanation is corroborated by an earlier study with dyslexic students whose task was to produce a written essay: no significant difference was found between the two groups concerning the total number of words written per minute (Sumner and Conelly 2020). Concerning pauses, our results are partially in line with previous studies (Sumner and Connelly 2020; Galbraith 1992; Galbraith et al. 2012). Indeed, some pause indicators are equivalent between the two groups: pause duration before a new line and before a clause. At a general level, these indicators do not show significant differences because students with dyslexia automate certain processes with age and exposure to 'the written world' (its culture, constraints, etc.) (Cavalli 2016), and specifically graphic structures and graphomotor gestures, which are independent of spelling abilities since the age of 10 (Bosga-Stork et al. 2016). That being said, the non-significance of differences for pause duration before clauses and new lines can also be due to the important inter-subject variability. Indeed, the students had no time constraints to complete their written text: this can be perceived as a limitation of our experimental protocol.

9.2 | Significant Results

The current investigation found significant differences between the two groups (students with dyslexia and control students) in terms of bursts, pause duration in general and pauses inside and between sequences (that means words and punctuation signs), between words, and before punctuation signs. First, results reveal significant differences for bursts (an indicator that takes together both words and long pauses). The students with dyslexia actually display shorter bursts: unlike the control students, they perform smaller writing sequences without pauses. The control students can write a longer series of words before they make a long pause, which supports the findings of other previous studies (Witko and Chenu 2019). As mentioned in the literature review, a long period of writing without pause reflects fluidity and quality in written productions (Alves and Limpo 2015; Limpo and Alves 2017; Witko and Chenu 2019). The students with dyslexia in our study do not display fluidity, and this can be evidence for some writing difficulties, such as spelling or planning. Second, several online pause indicators show significant differences between the two groups: pause duration in general, inter and intra-sequence pause duration, pauses inside and between words (confirming the analyses of Galbraith et al. 2012 and Wengelin 2007) and pauses before punctuation signs. For the first indicator, our results show that the students with dyslexia make longer pauses in their written texts than control students: this outcome is contrary to that of Sumner and Connelly (2020) who found that there was no significant difference between students with and without dyslexia. Moreover, the students with dyslexia make longer pauses before and inside words than the control students, which can reflect difficulties because, usually, the longer the unit is, the longer the pause is (Ailhaud and Chenu 2018; Foulin, Chanquoy, and Fayol 1989; Immonen and Mäkisalo 2017; Witko and Chenu 2019). So, these long pauses before and inside a word reveal a deficient spelling processing (Ailhaud, Chenu, and Jisa 2016; Witko and Chenu 2019). Previous works on the same sample reveal that although the students with dyslexia use the same types of word in terms of frequency, type, length or grapheme/phoneme and phoneme/grapheme consistency as the control students, they make much more spelling errors (Mazur, Quignard, and Witko 2021), in line with previous works in French (Mazur-Palandre 2018, 2019; Mazur, Quignard, and Witko 2021), English (among others, Hatcher, Snowling, and Griffiths 2002; Sumner and Connelly 2020) or Spanish (Afonso, Suárez-Coalla, and Cuetos 2015). So, these long pauses before and inside words can be due to persistent spelling difficulties: unautomated spelling requires important cognitive resources and this impacts writing fluency. Students with dyslexia need cognitive resources and time to have access to the spelling of words, and hence to handle transcription, as Witko and Chenu (2019) observe in their exploratory studies on French dyslexic teenagers. For the last indicator, our analyses show that pauses before punctuation signs are significantly longer in the texts of the students with dyslexia than in those of the control students. Pauses can be longer before punctuation marks because they involve important syntactic planning (Foulin, Chanquoy, and Fayol 1989), even more so for students with dyslexia. This result can confirm that they still have some difficulties with planning too. These findings are consistent with our observations in a previous study (Mazur and Quignard 2023), which showed that students with dyslexia have a deficient use of punctuation that may reveal deeper difficulties linked to higher-level processes involved in writing. Indeed, commas and periods play a role in the cohesion of a text and their management intervenes early in text writing, as soon as the text is linearised. The conclusion is that the lack of automation of spelling conversion impacts high-level processes such as planning or linearization, including punctuation. The present study provides further evidence supporting these previous observations: students with dyslexia make longer pauses before these punctuation marks, which indicates a slowdown in the processing of these marks, and therefore a certain difficulty in managing them. These two results taken together may corroborate the fact that the lack of automation for spelling impacts writing processes, even in adulthood. Moreover, we can notice that the difference in pause duration before punctuation signs is very important between the two groups: 1138 ms for the students with dyslexia and 493 ms for the students without dyslexia. Although other pauses (before words, for example) are also longer for the students with dyslexia, the difference in average is not so great. For instance, the average duration of pauses before words is 610 ms for the students with dyslexia, whereas it is 500 ms for the control students. For pauses before punctuation marks, the duration is more than doubled for the students with dyslexia, which supports our previous conclusion. Finally, the results concerning pause duration show that although pauses are longer in the written texts of students with dyslexia, they nevertheless respect the hierarchy identified for neurotypical writers (Ailhaud and Chenu 2018; Chanquoy, Foulin, and Fayol 1996; Foulin 1998; Schilperoord and Sanders 1999) and also for the control students in our study: pauses between paragraphs and clauses are on average longer than pauses between words.

To conclude, the fact that the transcription level stays an expensive process instead of being automated with age and experience (Berninger and Swanson 1994; Kellogg 1996, 1998) entails that the cognitive resources are shared between the three levels of writing: planning, translating and reviewing (Hayes and Flower 1980; Hayes 1996, 1998; Kellogg 1996, 1998). As the writing processing system is a capacity-limited system (McCutchen 1996), if cognitive resources continue to be allocated to the transcription level, planning and reviewing, which are at costlier levels (Hayes and Flower 1980; Hayes 1996, 1998; Kellogg 1996, 1998), are negatively impacted. In practical terms, this means, for instance, longer pause durations, longer pauses within and between words (and thus difficulties with the spelling conversion system, as part of the translating level), longer pauses before punctuation marks (as part of the planning level) and shorter bursts reflecting that the planning and translating levels are impacted. This study supports the idea that for students with dyslexia, the allocation of cognitive resources is modified by cognitive hindrances, and this impacts the transcription and planning processes. Spelling difficulties persist in adulthood and the lack of automation of the spelling conversion system continues to have consequences on both the planning and the transcription levels. Despite an early diagnosis, remediation and extensive exposure to the written world, students with dyslexia do not automate the spelling conversion system, and this hinders transcription and some processes of the planning level.

10 | Conclusion

The findings of our study are of theoretical and societal significance. First, our results reveal significant differences between the students with and without dyslexia in terms of bursts, pause duration, pauses within and between words and before punctuation signs, which may mean that their spelling difficulties continue to impact their transcription and planning processes, but less than children (Sumner, Connelly, and Barnett 2014) or teenagers with dyslexia (Witko and Chenu 2019). Significant results concerning bursts and pause duration suggest that they continue to have a problematic management of some aspects of the transcription and planning processes. This confirms that the allocation of cognitive resources is still altered by cognitive obstacles, and that the transcription process is still problematic and disorganises other high-level cognitive operations, which strengthens previous conclusions concerning teenagers with dyslexia (Witko and Chenu 2019). However, with the increase in their writing experience and practise as they grow up and with the development of their literacy skills, the impact of dyslexia on writing can be reduced. These elements therefore constitute important factors of protection. Indeed, results show that not all online indicators are impacted by dyslexia (handwriting speed, word rate, pause duration before new lines and clauses). The fact that students with dyslexia have the same handwriting speed and word rate as control students suggests that the spelling difficulties of students with dyslexia do not hinder some processes (linked with handwriting fluency) involved in the transcription process, as previously stated by Sumner and Connelly (2020).

Second, such results provide additional indications for completing the diagnosis of dyslexia and adapting the remediation as best as possible. Previous works also confirm the usefulness of using graphic tablets to capture online indicators, as they provide objective data on writing processes in daily practises. This enables to detect elements that cannot be spotted during a conventional work session with a patient (Brun-Henin et al. 2012; Witko and Chenu 2019). In addition, these online indicators allow us to better understand the cognitive operations involved (Witko and Chenu 2019).

11 | Limitations

Finally, we can raise two main limits in this study: (1) the use of the category of dyslexia without being able to distinguish the underlying deficits; (2) the absence of a test to verify the automation of graphomotor gestures. For the former, it in fact appears very difficult to precisely identify the types of deficits involved in adults (Mazur-Palandre, Abadie, and Bedoin 2016). For the latter, verifying the automation of graphomotor gestures (graphic skills only) would have made it possible to control purely graphomotor skills and isolate them from other writing skills, such as spelling. That said, it seems clearly established that while this is important in studies with children (among others, Martinez-Garcia et al. 2020), it appears to be less so when it comes to observing adults, who have already automated their motor gestures associated with writing itself (Bosga-Stork et al. 2016; Palmis et al. 2017).

Acknowledgements

We would like to acknowledge the ASLAN project (ANR-10-LABX-0081) of the Université de Lyon for its financial support within the French program 'Investments for the Future,' operated by the National Research Agency (ANR). We also thank the financial support device PEPS CNRS (Université de Lyon & CNRS) and the École Normale Supérieure de Lyon for its financial support within the 'Projets Émergents' program. Our gratitude extends to the students for their participation in this study, and to all collaborators involved in these dyslexia projects at the university: Agnès Witko, for her expertise in research and speech therapy; Raphaëlle Abadie, for her expertise as a neuropsychologist; Nathalie Bedoin, for her expertise in cognitive psychology; Florence Chenu, for her assistance with the software Eye and Pen; Louis Maritaud, for his meticulous data coding; and Céline Faure (MSH), for her statistical advice.

Conflicts of Interest

The author declares no potential conflicts of interest with respect to the research, authorship and/or publication of this article.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Endnotes

[1] A long pause lasts more than 2 s.

[2] For this reason, we decided to deal with these outliers. Outliers are values above Q3 + 3 IQR (Inter Quartile Range) or below Q1–3 IQR. This boundary is deliberately pushed further than required by the literature (Q3 + 1.5 IQR) to avoid skewing the data too much. Beyond these thresholds, pauses may be considered of a different nature to that of pauses of shorter duration.

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