Reading and Writing (2022) 35:1–27
https://doi.org/10.1007/s11145-021-10168-z

Pausing and breathing while reading aloud: development from 2nd to 7th grade in French speaking children

Erika Godde[1,2,3] · **Gérard Bailly**[1] · **Marie-Line Bosse**[2]

Accepted: 19 May 2021 / Published online: 26 May 2021

Abstract

Pauses when reading aloud play an essential role in reading and listening comprehension (for a review: Godde et al., 2020). Among the various types of pauses, breathing pauses during oral reading are particularly important. Their placement, frequency and duration tell us about breath and voice coordination as well as articulatory planning. These skills that develop over time, from the early stages of reading acquisition to skilled reading levels, are under-researched. The present study aims to describe how children develop the ability to use pauses during oral reading by comparing young French speaking readers ranging from second to seventh graders to adults. Voice and breathing patterns of 295 children and 20 adults were recorded during oral reading. Specific attention was given to the frequency, duration and placement of breathing pauses and inhalation to phonation delay. Our results revealed that the youngest students performed more ungrammatical pauses, breathed more frequently and produced longer inhalation to phonation delays. Children older than grade 4 were visibly more proficient at planning their pauses, particularly their breathing pauses, and tended to rely more on punctuation. Finally, pause planning observed for the grade 7 students was almost at adult level. This developmental study suggests that children's acquisition of pausing patterns during oral reading occurs gradually between the 2nd and 7th grades and highlights the important role of punctuation in planning breathing pauses and syntactic-prosodic breaks. Based on our results, we discuss the relation between pauses, decoding and expressivity, and develop didactic proposals for developing oral reading prosody.

Keywords Reading prosody · Breathing-voice coordination · Reading development · Pausing in reading · Breathing pauses

✉ Erika Godde
erika.godde@univ-grenoble-alpes.fr

[1] CNRS, Grenoble-INP, GIPSA-Lab, Université Grenoble Alpes, 38000 Grenoble, France

[2] CNRS, LPNC, Université Grenoble Alpes, 38000 Grenoble, France

[3] LPNC, Université Grenoble Alpes, BSHM 1251 av Centrale, 38058 Grenoble Cedex 9, France

Introduction

Reading aloud involves numerous cognitive processes: letter recognition, grapheme-phoneme mapping, semantic retrieval, syntactic extraction, articulatory planning, etc. An important part of children's reading acquisition process consists in learning to coordinate all these processes. In the first years of reading acquisition, reading instructors commonly focus primarily on developing automatic word decoding skills. Once a young learner's decoding skills become more automatic, their cognitive resources can be freed for other purposes such as developing reading comprehension (Samuels & Flor, 1997). The ability to add prosodic breaks during oral reading of a given text requires more advanced cognitive skills for adding appropriate intonation and planning pauses. Reading with adequate prosody entails using these skills effectively and indicates that the reader has successfully processed the meaning of the text (Kuhn, Schwanenflugel, & Meisinger, 2010). The process of planning prosodic structure before reading a text out loud often involves a delay, or a *processing* pause. In natural dialog, pauses play an essential role in organizing turn-taking in conversation and processing incoming semantic and pragmatic information. They help the listener to categorize the information into segments or thought groups that facilitate processing information being conveyed by the speaker. The specific nature of pauses in speech may also reveal the cognitive load of the speaker as, for example, longer pauses are typically associated with thinking and planning the next sequence (Brennan & Williams, 1995). Moreover, placement of pauses while reading, their duration and frequency have been shown to be closely linked to text comprehension (Arcand et al., 2014, in French; Molomer, Trausan-Matu, Dessus, & Bianco, 2015). Lalain, Legou, Fauth, Hirsch, and Didirkova (2016) proposed that, although silent, pauses are an integral part of the message being conveyed and deserve close attention. The present study aims to fill the lack of knowledge about the development of reading pauses in French children.

Pausing in reading aloud

To date, few studies have investigated the development of pausing patterns in reading (Godde, Bosse, & Bailly, 2020, for a review). Among those studies, Miller and Schwanenflugel (2006) and Schwanenflugel, Hamilton, Kuhn, Wisenbaker, and Stahl (2004), in English, and Álvarez-Cañizo, Suárez-Coalla, and Cuetos (2018), in Spanish, showed similar learning development patterns in the two languages that began with decoding acquisition and gradually moved toward the acquisition of the other reading skills, such as pause placement and frequency.

In adults, more data are available, mainly on pause duration and placement. Several authors found a multimodal distribution of pause durations in several languages. Campione and Véronis (2002) and Goldman, François, Roekhaut, and Simon (2010) showed a bimodal distribution of pause durations in text reading, distinguishing between brief pauses (< 200 ms, centered around 100 ms) and medium pauses (200–1000 ms, centered around 500 ms), in several languages (French,

German, English, Italian and Spanish). Bailly and Gouvernayre (2012) found even more modes in the distribution of pauses during the reading of an entire audiobook: besides short pauses (< 200 ms), three modes are associated with specific locations: sentence-internal (occurring at major syntactic boundaries or punctuation), end-of-sentence and end-of-paragraph pauses.

Characteristics of pause patterns (i.e., duration and placement) are linked to their numerous discursive functions such as signalling minor versus major syntactic boundaries, underlying cognitive processes, highlighting parts of the discourse, etc. A significant part of these pauses is also used to breathe, silently or not (Grosjean & Deschamps, 1975; Grosman, Simon, & Degand, 2018; Lalain et al., 2014). Moreover, different factors impact pausing patterns.

First of all, decoding skills induce pausing patterns. Indeed, adults make very few long hesitation pauses. In adult reading, 60% of pauses occur at the end of sentences (Grosjean & Deschamps, 1975; Grosman et al., 2018). In contrast, third graders tend to produce more intra-sentential pauses and within-word pauses than adults (Álvarez-Cañizo et al., 2018). Pausal intrusions, also called ungrammatical pauses, are intra-sentential pauses that do not cue syntactic boundaries, for example, between a noun and its specifier or adjective, after a preposition or within a word. Ungrammatical pauses, largely absent in adult reading, are in fact more common for young children and are mainly due to decoding difficulties. The frequency and duration of such inter- and intra-sentential pauses decrease rapidly from grade 1 to grade 3 (Godde et al., 2020) although at this level, and even at grade 5, it remains more frequent than in adults.

Pausing patterns in oral reading depend as well on the individual's reading skill level: compared to fluent readers in the same grade, less fluent readers (i.e., having a number of words correctly read in a minute inferior to their age average) tend to make more frequent and longer pauses, and produce more ungrammatical pauses (Godde et al., 2020). When sentences are ambiguous or complex, children, as adults, tend to emphasize their prosody, and produce more frequent and longer syntactic pauses (Benjamin & Schwanenflugel, 2010; Kentner & Vasishth, 2016).

Pausing patterns in adult reading are also closely linked to the text punctuation (Campione, Véronis, & Delic, 2002; Martin, 2011). Like adults, young children appear to rely more heavily on punctuation to plan their pauses than older, more experienced readers. However, the motivation may be different. Miller and Schwanenflugel (2008) proposed that this may be due to a decrease of motivation to be bound to punctuation as reading skills improve in primary grades, while in adults, punctuations are used as landmarks for expressive prosodic patterns.

Finally, as Grosjean and Collins (1979) reported in their study of pausing in adults, Breznitz (1990) showed that pausing patterns in children are also at least partially dependent on reading speed. Increased reading speeds corresponded to fewer and shorter pauses.

To sum up, with pauses placed as boundary-markers and associated with punctuation, adult pausing patterns rely on look-ahead planning of breathing opportunities and more advanced cognitive resources for processing syntactic structure that children do not yet master. The studies presented here describe the development of pauses planning in young readers. However, to our knowledge, no studies have

investigated development of pauses in young readers older than primary school age but who have clearly not fully matured as skilled oral readers.

Breathing while reading

Among the various types of pauses, breathing pauses are essential and incompressible. In both spontaneous speech and reading, in order to match the syntax of the text, the reader's breathing must be carefully planned to effectively meet both physiological and syntactic requirements.

Wlodarczak and Heldner (2017) showed that the syntactic structure is predominant over the physiological needs during spontaneous speech. Adults are able to continue talking as long as they have enough air in their lungs to complete the next utterance (Wang, Green, Nip, Kent, & Kent, 2010). There seems to be no adaptation of the syntactic structure to the breathing needs. However, when the speaker hesitates during spontaneous dialogs, breathing pauses can be longer and less grammatical. Anticipation of the next utterance becomes difficult because the cognitive load increases and the syntax is less structured. These hesitation pauses are often present during adult spontaneous speech but rare during adult reading, with less than 2% of inappropriate breathing pauses (Wang et al., 2010).

In oral reading, the distribution of pauses is highly constrained by the text structure. Bailly and Gouvernayre (2012) analyzed the pausing and breathing coordination of one French reader of audiobooks and observed that 70% of medium and long pauses were breathing pauses. They also showed that breathing noises are used as supplementary discourse markers (i.e. signalling rheme vs. theme structure), supporting the importance of planning breathing pauses in reading. As mentioned earlier, Grosjean and Collins (1979) showed that reading speed impacts pausing patterns, more specifically that reading aloud rapidly changes breathing patterns and consequently impacts pausing. As reading speed increases, the frequency and duration of non-respiratory pauses initially decrease. In a second phase, if the reading rate increases, the number and duration of the breathing pauses decrease further. Breathing pauses can be divided in three phases: pre-inspiration, inhalation and post-inspiration. When reading speed increases, the pre-inspiration phase tends to disappear. In adults, inhalation always occurs at the end of the breathing pause. Bailly and Gouvernayre (2012) measured the inhalation to phonation delay (IPD) of adults and found a mean IPD of 355 ms (SD = 145 ms). Moreover, IPD is not linked to pause duration, but is more related to the length of upcoming sentences. According to Grosjean and Collins (1979), in reading measured at a standard rate, breathing patterns will depend on preplanned pause opportunities and the rhythmical balance between speech chunks. As the reading rate increases, physiological needs take over planning and patterns of breathing pauses are no longer strongly linked to the syntax but almost exclusively depend on inhalation demands.

Coordinating breathing and text reading thus presents a specific challenge in the context of developing pause planning skills in reading. Children must learn to arbitrate between the need to breath and to align with the syntactic structure of the text. They need to learn to anticipate what's coming next in the text and learn to use

punctuation as air-intake opportunities. Breathing coordination during oral reading is particularly challenging for children to master and breathing-speech coordination has been shown to progressively develop between 3 and 10 years of age. While the number of syllables pronounced in one exhalation gradually increases, the level of difficulty coordinating breath inspiration with linguistic or communicative purpose decreases (Boliek, Hixon, Watson, & Jones, 2009). It has also been shown that a boost in progress tends to occur between 7 and 8 years (Hoit, Hixon, Watson, & Morgan, 1990) and important inter-individual variability in developing these skills is also at play (Boliek et al., 2009). In short, for children beginning to read around 6 or 7 years of age, lung capacity and speech-breathing coordination are not yet fully matured.

Despite the critical role of pausing and breathing during reading, surprisingly little attention has been dedicated to describing the development of breathing patterns in oral reading. Among the few studies that have investigated this aspect of oral reading, one study focused on children with and without asthma (Wiechern, Liberty, Pattemore, & Lin, 2018) while another study focused on children with and without dyslexia (Lalain et al., 2014). Dyslexic children tend to make longer and more frequent pauses with more intra-word pauses than the control children because of a lack of automation of the reading process (Lalain et al., 2014). Similarly, children with asthma tend to make longer, more frequent breathing pauses, especially when reading complex texts (Wiechern et al., 2018). For the control groups in both studies, the authors observed that fewer but longer breathing pauses were produced during the reading of difficult texts.

Two methods are generally used for measuring respiratory rates or breath intakes during speech pauses. The first approach consists of simultaneously recording speech and breathing movements such as Rochet-Capellan et al. (2014) used in their study on adults in which they had participants wear breathing vests or belts secured around the abdomen and chest area that were then synchronized with voice audio signals. Wiechern et al. (2018) opted for a second approach: they relied on sound recordings to identify breathing pauses. These authors felt using belts would be too intrusive and instead used close microphones to record breathing sounds made by the reader, which allowed them to isolate specific breathing patterns. For our own purposes, we chose to combine both methods; we took audio recordings of the children in our study while they read aloud wearing respiratory belts. As we were more interested in the frequency of air intakes rather than the precise volume of inspiratory airflow, we were able to avoid an additional calibration phase using a mask-like device we felt would be too invasive. The belts we asked the children to wear did not need to be excessively tight to record accurate breathing movements and none of the children expressed concern about wearing them during the exercise of reading aloud. These methodological choices allowed us to accurately measure the children's' breathing and let the young children focus on their reading and not be distracted by the recording devices.

The primary purpose of our study is to precisely characterize the development of pausing in reading from grade 2 to grade 7, by clearly differentiating breathing and non-breathing pauses. To do this, we focused on four core perspectives of pausing during reading. We began by considering pause durations and its contingent

mutimodal distribution, as observed in adults (Campione & Veronis, 2002) and anticipated that this would reveal two separate modes, short and long pauses, that develop in parallel with reading acquisition. Secondly, we focused on the number or frequency of pauses. According to literature (Godde et al., 2020), we hypothesized that the number of long pauses would decrease rapidly in the initial years of learning (reading acquisition) and that the number of ungrammatical pauses would be adult-like for pupils of primary school age. Thirdly, we concentrated specifically on breathing pauses we identified and measured by using two respiratory belts providing us with frequency, duration and their planning through the inhalation to phonation delay. Our hypothesis here is that the number of breathing pauses would decrease up to the end of primary grades when breathing patterns begin to mature (Boliek et al., 2009) and should be adult-like in grade 6 and 7. Ungrammatical breathing pauses should be frequent in the first years but should quickly disappear. Concerning the duration of breathing pauses, we anticipated mostly longer pauses, and that the inhalation to phonation delay would decrease as reading skills developed. Finally, we considered the potentially important role punctuation marks play in terms of planning pauses during oral reading. Here, we expected that younger children would rely more heavily on punctuation as signals to pause and breathe than older children and adults, particularly when navigating longer, more complex sentences (Miller & Schwanenflugel, 2008).

Method

This study took place in two primary schools and one middle school located in the urban area of Grenoble (France). Our protocol was approved by the ethics committee (CERGA, ethic committee of Université Grenoble Alpes) and the local representatives of the French Ministry of Education.

Participants

Audio recordings of oral readings were made for 323 students ranging from grade 2 to grade 7 from 14 classes in three different schools. Authorization release forms signed for by each participating student's parent(s), teacher and school director were obtained prior to the recordings. For the purpose of this study, data collected from 4 children presenting severe dyslexia and from 16 children who were not native French speakers were discarded. Addition data from 8 children whose recordings were unusable due to sampling issues were also excluded. A total of 295 children were included in the dataset. Table 1 presents the characteristics of the children for each grade (number, age, gender), together with their reading level expressed in the number of correct words read per minute (CWPM; Maeder, Roustit, Launay, & Touzin, 2018) and their non-verbal reasoning level measured with the PM38 test (Raven, 2003). Both scores are congruent with the children's age according to established standards.

Table 1 Characteristics of the participants according to their grade level: Means (standard deviations) with CWPM and PM38 mean ref score

Grade	2	3	4	5	6	7	Adults
Number	61	47	54	63	33	37	20
Females	27	25	26	23	15	21	10
Mean age	7:11(3.8)	8:11(3.4)	9:11(5.1)	10:11(4.5)	11:11(4.8)	12:8(5.4)	29:6(85)
Scope	(7:2–8:5)	(8:5–9:5)	(8:5–10:5)	(10:3–12)	(11:4–13)	(11:8–13:9)	(21:58)
CWPM	58(22)	80(31)	100(30)	108(42)	116(30)	143(76)	NA
CWPM ref	68	90	120	133	NA		
PM38	33.6 (9)	37.5 (8)	39.7 (6.8)	43.7 (6.8)	38.6 (5.9)	41.5 (6.3)	NA
PM38 ref	33	36	40	41	38.9	42	NA

Age is expressed in years: months

CWPM = number of words correctly read per minute

Oral readings of the same text by 20 adults were also recorded as references. These individuals were recruited in the lab on a voluntary basis. Sixteen of them have a university degree, four of them are graduate students. All adults were assessed as expert readers using a multidimensional fluency scale (Godde et al., 2021).

Material

The participants were asked to read a text written for the specific purpose of the experiment and based on a short story for children (Friot, 2007). This is a 174 words narrative text with 13 declarative sentences each containing between 7 and 18 words. Among the 8 long sentences (> 12 words), 4 had no comma and 4 included commas (2 or 3 per sentences) to help distinguish phrases within the sentence. The long sentences included 2.5 ± 0.5 clauses with 4.8 ± 1.2 words per clauses. The average lexical frequencies of both long sentence types are equivalent (Lété, 2004), 4528 occurrences for a million word ($SD = 325$) for the sentences with punctuation marks and 4406 occurrences for a million words ($SD = 340$) for the others. The text is presented in Appendix 1. An example of expected pauses in few sentences is presented in Fig. 1.

… Alors le chat s'est frotté sur ma jambe, il a miaulé, il était désolé. Finalement il m'a aidé et on a préparé ensemble un bel exposé sur l'intelligence des chats.

Fig. 1 Extract of the text used in this experimennt. In gray an exemple of pauses expected in those two sentences

Procedure

The children were recorded on location at their respective schools where they were asked to read in a quiet room near their classrooms. The text they were asked to read aloud (described below) was presented to them at the time of each recording session in a counterbalanced order with another text used in another study. The adults were recorded in an experimental room in the lab where we followed the same procedure. All participants were recorded on their first reading of the text and were given no opportunity to prepare or rehearse.

We asked our participants to read "as if they were reading a story to a preschooler". This instruction was intended to (1) encourage an expressive reading and (2) to ensure that it would be understood by the youngest readers. Indeed, young readers may not have a clear idea of what reading with expressivity means, but they are familiar with reading for younger children. During each oral reading, we recorded participants' voice and breathing movements. Voice audio was recorded using a Schur Beta 53 headset microphone with a Behringer MIC100 amplifier. The breathing movements were recorded with two respiratory belts RESP150 placed on the thorax and the abdomen. Speech and belts signals were synchronously acquired with a Biopac MP150. The close headset microphone allowed us to capture mouthing and audible breaths prior to vocalization, if appropriate.

Data preparation

The audio signals were automatically aligned to the text with a statistical model with phonetic triphone models, pronunciation dictionary and trigram model. As the children's' readings contained numerous pronunciation errors, omissions, hesitations and occasional repetition, each alignment was then manually corrected using Praat (Boersma & Weenink, 2020).

The pauses were annotated as either breathing or non-breathing pauses, using the audio clue of air intakes and the respiratory belts signals. For breathing pauses, we also annotated the inhalation-to-phonation delay (IPD), as shown in Fig. 2. As a result, we collected 16,895 pauses from the 315 total readings, among which 8900 were annotated as breathing pauses.

Data analyses

For each participant, various parameters concerning pause durations (mean duration, within-participant variability) and frequency, number of pauses per word (all pauses, ungrammatical pauses, pauses occurring at punctuation marks and pauses in long sentences with and without intra-sentential punctuation marks) were extracted and computed. After standard global analyses of all pause durations and all pause frequencies, we focused on breathing pauses (frequency, duration and IPD). We also

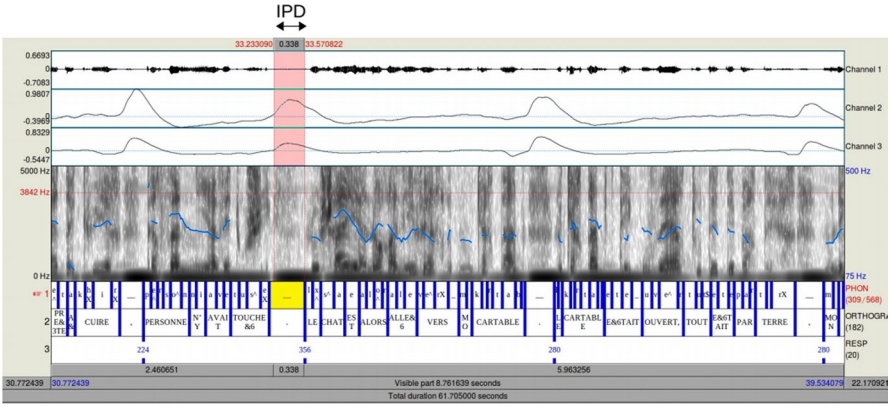

Fig. 2 Praat screenshot showing audio signal on channel one, respiratory belt signals on channel 2 (abdominal) and 3 (thoracic) and annotations of phonemes and pauses, words and inhalation to phonation delay (IPD). IPD was measured manually using audio and belts signal

computed total reading and pausing time, as well as the number of words correctly read in a minute (CWPM) reflecting accuracy and fluency.

All parameters were retrieved and analysed using R (Team, 2019). The duration data were log-transformed before analysis (Campione & Véronis, 2002). We tested the effect of grade level using hierarchical linear mixed effect model with lmer function (lme4 R package, Bates, Mächler, Bolker, &Walker, 2015). As the participants were from 14 different classrooms, the classroom itself was introduced as a random effect of level 2. This random effect of classroom was significant for every parameter tested (intra class correlation > 0.05), except for one. For each parameter, we compared the empty model and the model with the grade level as a fixed factor, using Analysis of variance (ANOVA). We then reported the significance of grade level with $\Delta\chi^2$ (ddl) and p value. When the grade level had a significant effect on the parameter, we tested the significance of differences between grade level side by side, using the Tukey post-hoc test. We then reported the highest p-value among all tests performed. Finally, we reported mean and standard deviation for each group and each parameter. When there was no significant difference between groups, we gathered the groups and report the mean and the standard deviation of the cluster.

Results

Total reading and pausing time

We began by analyzing the total reading time both in terms of pauses and words read. The grade level had a significant effect on total reading time (see Fig. 3a; $\Delta\chi^2(6) = 39.4$, $p < 0.001$). In 2nd grade, the mean total reading time was 125 s ($SD = 40$ s). It decreased significantly in grade 3 ($p < 0.001$) to reach 106 s ($SD = 50$ s), and in grade 4 ($p < 0.03$) to stabilize at 68 s (SD = 18 s) until

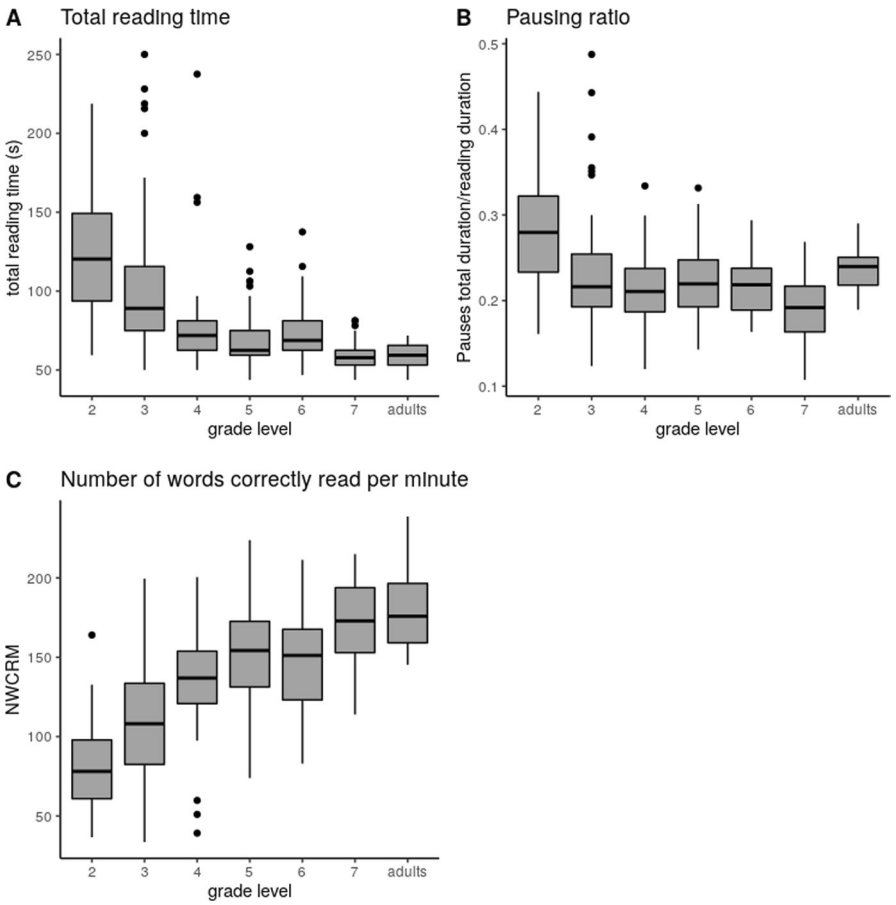

Fig. 3 Boxplots of total reading time, pausing ratio and number of words correctly read in a minute for each grade level and adults

6th grade. The total reading time was therefore similar to 7th grade and adults ($M = 60$ s, $SD = 9$ s).

The total reading time depended on the total pausing time and on the reading speed. Accordingly, we computed the ratio of total pausing time on the total reading time and the number of words correctly read in a minute (CWPM). The grade level had a significant effect on the pausing/reading ratio (see Fig. 3b; $\Delta\chi^2(6) = 31$, $p < 0.001$). In 2nd grade, children spend 28% ($SD = 0.06$) of reading time pausing. This ratio decreased in grade 3 ($p < 0.001$) to stabilize at 22% ($SD = 0.04$). From grade 3, the ratio of pauses during reading time was adult-like. The grade level had a significant effect on the CWPM (see Fig. 3c; $\Delta\chi^2(6) = 49$, $p < 0.001$). The CWPM increased drastically from grade 2 ($M = 81.4$, $SD = 26.8$) to grade 3 ($M = 108.8$, $SD = 39.3$; $p < 0.04$) and grade 4 ($M = 135.6$, $SD = 31$;

$p < 0.01$). The CWPM then stabilized until 6th grade (M = 145, SD = 30). In 7th grade, the CWPM was adult-like ($M = 175$, $SD = 25$).

To summarize, reading speed and fluency increased rapidly from grade 2–4, to reach adult-like values in grade 7. Nevertheless, the pausing/reading ratio was adult-like as soon as 3rd grade.

Pause duration

Figure 4 shows the distribution of log duration of pauses for each level. A Shapiro–Wilk test showed that, at each level, the distribution of pause durations is significantly different from the normality ($p < 0.001$ for each level). In accordance with previous studies (Bailly & Gouvernayre, 2012; Campione et al., 2002; Goldman et al., 2010), the distribution was bimodal at every level. We approximated the bimodal distributions using Gaussian Mixture Model with the normalmixEM function of the mixtools package (Benaglia, Chauveau, Hunter, & Young, 2009). The models converged for each level. The parameters calculated for each approximation are presented in Table 2 and plotted on Fig. 4.

As our data were fitted with bimodal distributions as recommended by Campione and Véronis (2002), a distinction was made between short pauses (SP) centered around the first gaussian (on average around 125 ms) and long pauses (LP) centered

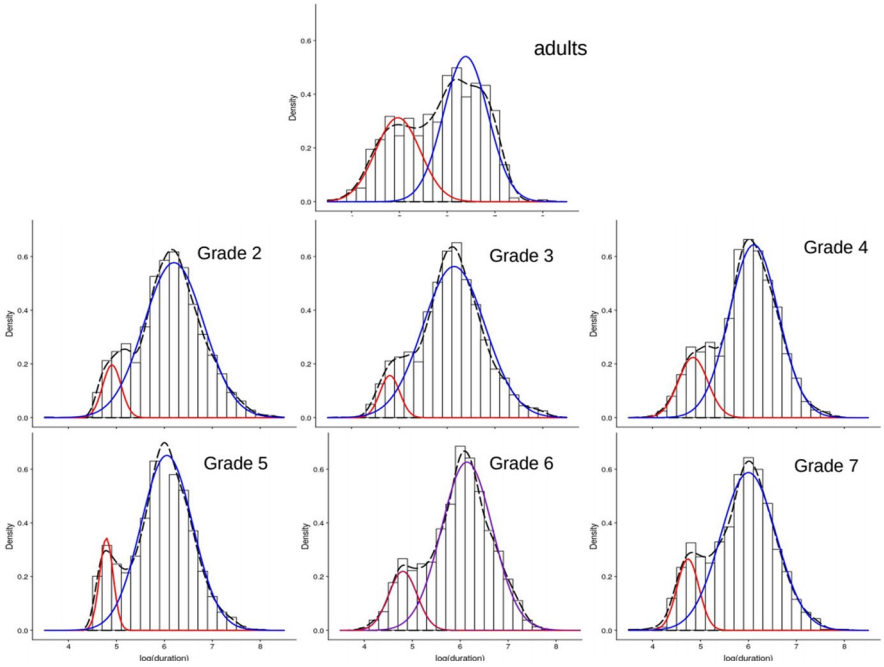

Fig. 4 Distribution of log duration pauses for each grade level: histograms and density curves (dashed line). Distributions have been approximated using a mixture model of two Gaussians (short pauses = red line, long pauses = blue line). (Color figure online)

Table 2 For each grade, parameters of Gaussian mixture models for log duration pauses: λ, μ, σ, computed using nomralmixEM function of the R mixtool package; with corresponding mean in ms (M) and threshold between short and long pauses (T) corresponding to the pass of the Gaussian mixture

	Grade													
	2		3		4		5		6		7		Adults	
	SP	LP	SP	LP	SP	LP	SP	LP	SP	LP	SP	LP	SP	LP
λ	.096	.904	.081	.919	.173	.827	.121	.879	.163	.837	.152	.847	.366	.633
μ	4.91	6.20	4.80	6.15	4.84	6.11	4.79	6.05	4.80	6.14	4.74	6.00	4.97	6.38
σ	.193	.625	.206	.651	.306	.512	.141	.538	.295	.533	.228	.575	.467	.466
M (ms)	135	492	122	466	126	450	120	424	121	464	114	403	144	589
T (ms)	220		190		220		200		200		180		220	

around the second gaussian (on average around 470 ms). For the next stage of our analysis, we drew a threshold line between SP and LP. As shown in Table 2, the means of Gaussians are different from on grade to another. To take that difference into account and to precisely classify pauses, the threshold between SP and LP was defined separately for each grade, as the distribution minimum between the two Gaussians. Thresholds for each grade are presented in Table 2, together with the mean duration of each type of pause. Our results are in line with those of Campione and Véronis (2002) and Bailly and Gouvernayre (2012).

We then looked at the effect of the grade level on pause duration. The grade level had a significant effect on both SP ($\Delta\chi^2(6)=40.5$, $p<0.001$) and LP ($\Delta\chi^2(6)=28.7$, $p<0.001$) mean durations. Overall, pause duration tended to decrease with grade and to be longer for adults than for the oldest children (see Fig. 5a, b). More precisely, the Tukey test on SP showed that 2nd graders, 4th graders and adults produced significantly longer SP ($M=151$ ms, $SD=14$) than the 3rd, 5th and 6th graders ($M=136$ ms, $SD=13$; $p<0.001$). Seventh graders produced significantly shorter SPs ($M=130$ ms, $SD=10$) than any other group ($p<0.029$). The Tukey test on LP revealed that 2nd graders and adults had significantly longer LPs ($M=630$ ms, $SD=117$) than children in grades 3–7 (from grade 3 to 7: $M=528$ ms, $SD=103$; $p<0.001$).

The effect of grade level is also significant on the within-participant variability (i.e., standard deviation). For SP variability (see Fig. 5c; $\Delta\chi^2(6)=37.5$, $p<0.001$), the grade effect seemed to follow the same pattern as we observed for duration: 2nd graders, 4th graders and adults produced less regular SPs than children in higher grades. The grade level also had a significant effect on within-participant variability of LP duration (see Fig. 5d; $\Delta\chi^2(6)=30.9$, $p<0.001$), essentially due to the high variability of LP duration observed among second graders ($M=373$ ms, $SD=135$) compared to other grade levels and adults ($p<0.024$). This effect might be explained by the fact that the youngest readers produced numerous hesitation pauses. Older children produced more regular LPs. It is also worth noting that the adults exhibited significantly more variation in their LP duration ($M=293$, $SD=94$) than children between grades 4 and 7 ($M=244$, $SD=102$; $p<0.04$).

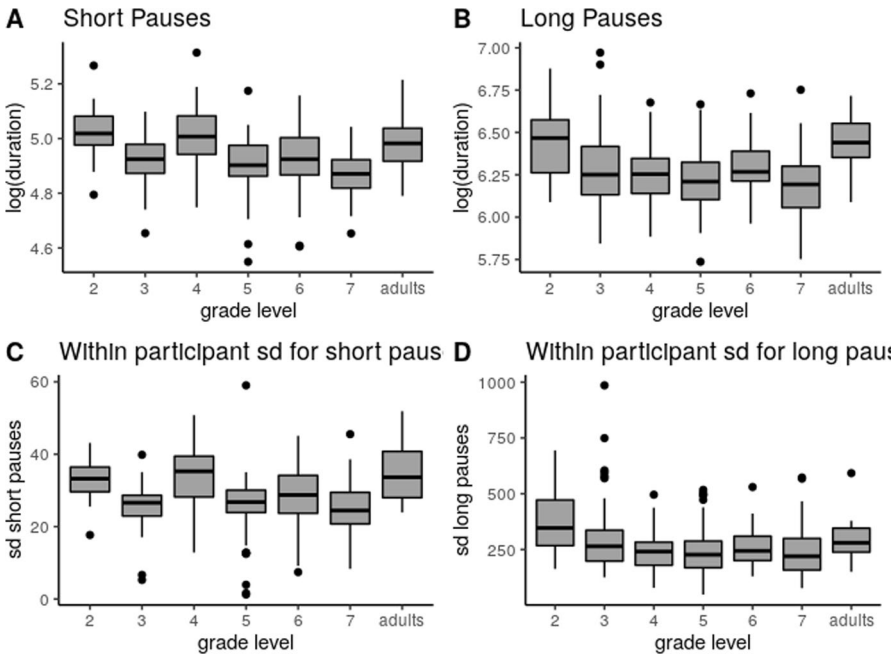

Fig. 5 Boxplots of pause durations corresponding to grade level, for short pauses (SP) in **a** and long pauses (LP) in **b**. Evolution of within-participant variability (standard deviation) according to grade level for SP in **c** and LP in **d**

To summarize here, the distribution of pause duration appears to be bimodal as soon as 2nd grade. This prompted us to study SPs and LPs separately. For LPs, 2nd graders and adults tended to produce pauses with longer duration compared to other children. For SPs, we did not observe any clear tendency.

Pause frequency

We specifically considered numbers of SPs and LPs per word of the text, i.e., pause frequency, as a barometer for bimodal distribution of pauses durations. Grade level had a significant effect on the frequency of both SPs ($\Delta\chi^2(6) = 28{,}79$ $p < 0.001$) and LPs ($\Delta\chi^2(6) = 35.83$, $p < 0.001$). The overall number of SPs and LPs decreased with grade level (see Fig. 6a, b). More precisely, the Tukey tests showed that second graders produced SPs more frequently ($M = 0.09$, $SD = 0.04$) than all other participants ($p < 0.001$). From grade 3 to adults, there was no significant difference between grade levels ($M = 0.05$, $SD = 0.03$). The developmental pattern of LPs slightly differed: second and third graders produced more LPs ($M = 0.36$, $SD = 0.20$) than both the older children and adults ($p < 0.001$). The frequency of LPs remained stable for students in grades 4–7 and adults ($M = 0.17$, $SD = 0.05$). It is worth noting here that variability of LP number among students in one grade was particularly high in grades 2 ($SD = 0.18$) and 3 ($SD = 0.21$) and decreased fairly significantly after grade

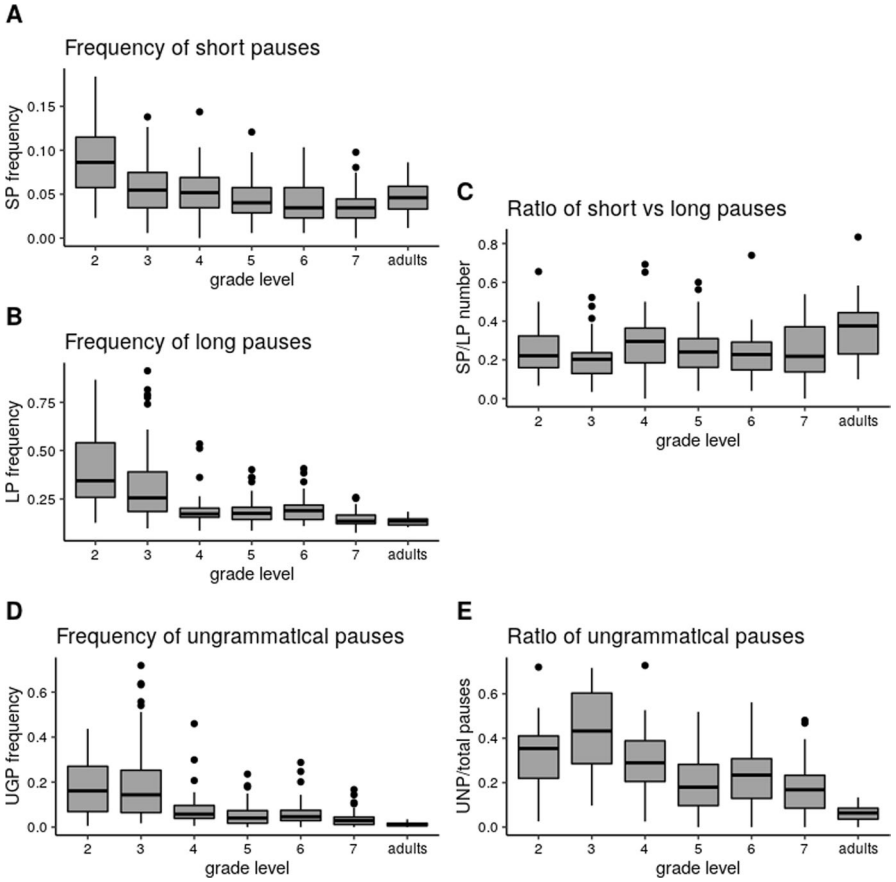

Fig. 6 Boxplots of pauses frequency according to grade level: frequency of short pauses (**a**), long pauses (**b**) and ungrammatical pauses (**d**) according to grade level, ratio of short and long pauses (**c**), ratio of ungrammatical pauses (**e**) according to grade level

4 ($SD < 08$). This observation confirms the degree of variability of reading skills in the first year of reading. Grade level also had a significant effect on the ratio of SPs versus LPs [see Fig. 6c; $\Delta\chi^2(6) = 29.79$, $p < 0.001$]. Adults made significantly more short pauses compared to long pauses ($M = 0.37$, $SD = 0.17$) than children ($p < 0.014$).

Ungrammatical pauses (UP) are interesting in that they indicate a lack of planning and anticipation or decoding difficulties. Speakers tend to place this type of pause, for example, between a noun and its specifier or adjective, after a preposition or within a word. Our results showed that grade level was strongly correlated to UP frequency [see Fig. 6d; $\Delta\chi^2(6) = 33.5$, $p < 0.001$]. The frequency of UPs produced by second and third graders ($M = 0.18$, $SD = 0.15$) was roughly three times higher ($p < 0.001$) than by the other children. Their frequency then dramatically decreased in fourth graders and stabilized in children in grades 5–7 ($M = 0.06$, $SD = 0.05$;

$p < 0.003$). The adults did produce a limited number of UPs, while the frequency was close to zero. Indeed, our recordings of the participants' first readings of the text revealed that decoding difficulties also occurred for some adults. We also looked at the ratio of ungrammatical pauses among all the pauses (see Fig. 6e). Grade level had a significant impact on this ratio [$\Delta\chi^2(6) = 37.7$, $p < 0.001$]. Although we expected the ratio to decrease from grade 2 to grade 4 and then stabilize with the acquisition of automaticity, our data showed a significantly higher ratio in third graders ($M = 0.44$, $SD = 0.18$) compared to second graders ($M = 0.32$, $SD = 0.13$; $p < 0.001$). The ratio decreased in fourth graders ($M = 0.29$, $SD = 14$; $p < 0.001$) and stabilized in children from grades 5–7 ($M = 0.20$, $SD = 0.13$). However, it remained higher than the ratio we observed in adults ($M = 0.06$, $SD = 0.03$; $p < 0.001$). The ratio in seventh graders was not yet adult-like. Variability in UP frequency between participants was particularly high in second and third graders (respectively, $SD = 0.13$ and 0.18). Once again, this could be due to the variability of reading skills during the first years of reading acquisition.

Overall, SP and LP frequency decreased and seemed to level off in children from grade 4 onwards. The number of LPs produced by seventh graders was adult-like but they produced fewer SPs than the adults in this study. Our results show that ungrammatical pauses often occurred in the initial years of reading acquisition and occurred more frequently still in seventh graders than in adult readers.

Breathing pauses (BPs)

We first looked at the proportion of BP among the short and long pauses. BPs are almost always LPs and, on average, represent roughly 70% of the total LPs. Among the 8900 BPs analysed, only 15 were classified as SPs. Due to this marginal number, we decided therefore to study BPs with no cleavage between short and long pauses. In the next stage of analysis, we considered BP as one type of pause (that might include a small proportion of SP). The grade level had no significant impact on the BP ratio [see Fig. 7b; $\Delta\chi^2(6) = 9.95$, $p = 0.12$] which was around 58% ($SD = 0.13$) of the overall number of pauses. Grade level, however, appeared to have a significant effect on BP frequency [$\Delta\chi^2(6) = 37.6$, $p < 0.001$). BPs decreased dramatically in children from grade 2 to grade 4 (see Fig. 7a). Grade 2 children produced significantly more BPs ($M = 0.26$, $SD = 0.10$) that children from grade 4 and adults ($p < 0.001$), which we also observed in the third graders ($M = 0.20$, $SD = 0.10$; $p < 0.05$). The number of BPs levelled off in younger readers from grades 4 to 7 and for adults ($M = 0.12$, $SD = 0.04$).

Grade level also had a significant effect on BP duration [see Fig. 7c; $\Delta\chi^2(6) = 23.7$, $p < 0.001$]. Given that BP represents 70% of the LP, it was not surprising when we observed the same pattern as for LP duration: BP duration for second graders and adults ($M = 715$, $SD = 160$) significantly longer ($p < 0.022$) than BP duration in children from grades 3–7 ($M = 588$, $SD = 161$). To take a more precise look at BP patterns, we focused specifically on the inhalation to phonation delay (IPD). Grade level also had a significant effect on IPD [see Fig. 7d; $\Delta\chi^2(6) = 23.7$, $p < 0.001$]. In second graders, IPD was significantly higher ($M = 529$, $SD = 117$; $p < 0.001$) than

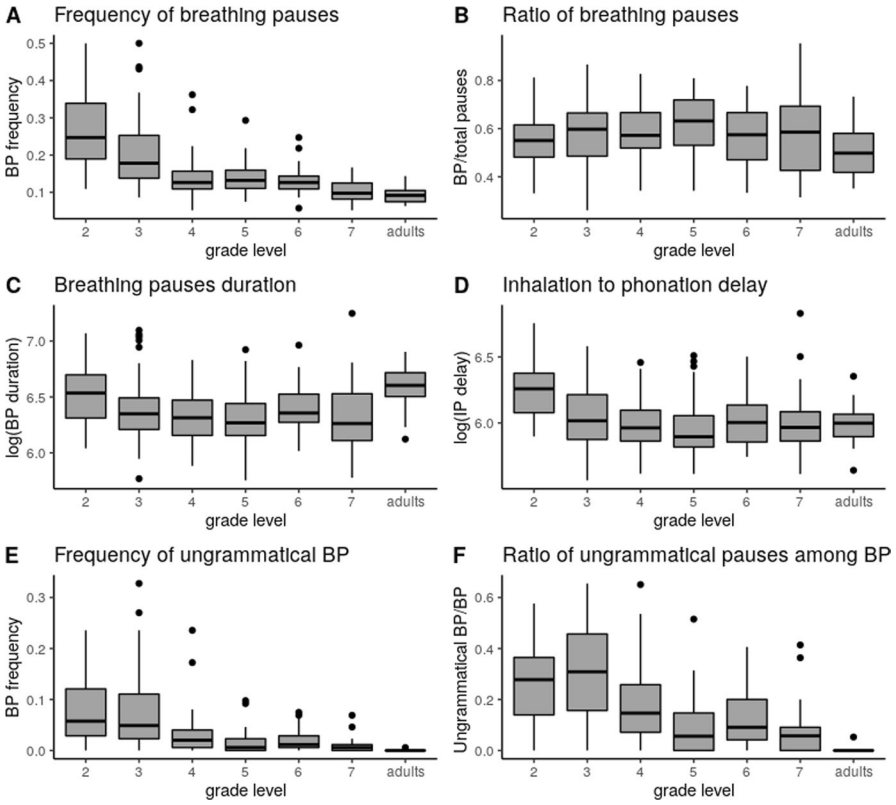

Fig. 7 Boxplots of breathing pauses from grades 2 to grade 7 and adults: frequency of breathing pauses (BP) (**a**), percentage of BP among the total pauses (**b**), BP duration with log transformation (**c**), inhalation to phonation delay (IP) after log transformation (**d**), frequency of ungrammatical BP (**e**) and ratio of ungrammatical pauses among BP (**f**)

in children from the other grades and adults ($MD = 413$, $SD = 110$). Second graders were less competent at consciously planning their BPs and simply tended to breathe as soon as they finished talking instead of inhaling before they began. Adults always inhaled just-in-time before beginning to speak and exhibit an average IPD of around 400 ms ($SD = 66$). Second graders made longer BPs, which appeared to be caused by longer IPDs, revealing a lack of planning. Adults produced IPDs similar to children from grades 3 to grade 7, but they made a longer pre-inspiratory pause, leading to a longer BP. We observed that children older than grade 4 had adult-like BP profiles. As for LP duration, the IPD and BP internal duration variability in each subject is affected by grade level (IPD: $\Delta\chi^2(6) = 42.7$, $p < 0.001$; BP: $\Delta\chi^2(6) = 29.9$, $p < 0.001$). The pattern was the same for internal variability: a high variability in second graders (IPD: $M = 299$, $SD = 128$; BP: $M = 376$, $SD = 158$), that extended to third graders (IPD: $M = 206$, $SD = 111$; BP: $M = 310$, $SD = 200$) and decreased in older children (IPD: $M = 159$, $SD = 80$; BP: $M = 237$, $SD = 101$), supporting a lack of anticipation in the first year of reading acquisition.

To assess breathing coordination and planning, we looked at the frequency of ungrammatical BP (UBP). Indeed, if the BPs are planned, they should support the syntactic organization of the text and be grammatical. As expected, the grade level had an impact on the frequency of UBPs (see Fig. 7e; $\Delta\chi^2(6)=32.3$, $p<0.001$). Children in grades 2 and 3 made significantly more UBP pauses ($M=0.08$, $SD=0.06$) than the others ($p<0.001$). The number of UBP was divided by three in the case of fourth graders ($M=0.03$, $SD=0.04$; $p<0.02$). It then levelled off in children from grade 5 to grade 7 ($M=0.02$, $SD=0.02$). BP planning appears fairly established in fourth graders, even if not completely adult-like, probably because of late decoding issues. Finally, to confirm this observation, we computed the ratio of ungrammatical pauses among BPs. Again, grade level had a significant effect [see Fig. 7f; $\Delta\chi^2(6)=36.7$, $p<0.001$]. This ratio was significantly higher in children from grades 2 and 3 ($M=29\%$, $SD=0.16$) than for older children ($M=18\%$ in fourth grade, $p<0.001$). The ratio continued to decrease and levelled off at 9% for children from grades 5 to 7. For the adults, the ratio was null, expressing perfect coordination of breathing during oral reading.

In summary, BP patterns appeared to develop in parallel with other reading skills (e.g., decrease of UP and IPD), and lung development (e.g., decrease of pauses number). Indeed, we observed the same pattern of development with a decrease in each parameter's values from grade 2–4, followed by almost adult-like performance from grade 5–7. However, even in grade 7, errors in breathing planification were still observed while none were found in adults.

Punctuation effect on pausing patterns

As previously reported by Martin (2011), punctuation marks in written language are important landmarks for prosodic patterns (pauses, boundary tones, etc.). In this study, we examined how children use punctuation to locate their pauses and breathing when reading aloud. We also compared the occurrence of ungrammatical pauses in long sentences with and without intra-sentential punctuation marks. Our hypothesis was that children use punctuation marks as visual aids for planning pauses, and consequently, that young readers would be more likely to produce ungrammatical pauses while reading sentences with no punctuation.

To test this hypothesis, we first looked at the number of pauses occurring at punctuation marks. The text we asked participants to read aloud included a total of 22 punctuation marks (9 commas and 13 periods). As shown in Fig. 8a, nearly all punctuation marks were followed by a pause. Our results showed a close correlation between grade level (age, reading expertise) and the number of these pauses occurring at punctuation marks [$\Delta\chi^2(6)=20.7$, $p=0.002$]. The adults in our study paused at every punctuation mark ($M=21.6$, $SD=0.9$) while the children readers skipped a few of these cues ($M=19.5$, $SD=2.7$) ($p<0.001$), more commonly commas. We then looked more closely at the types of pauses occurring at punctuation marks (see Fig. 8b, c). Most of these pauses at punctuation marks were LPs (81% on average) and BPs (77% on average), with SPs occurring only rarely. Grade level also had a significant effect on the ratio of BPs among punctuation pauses [$\Delta\chi^2(6)=20.7$,

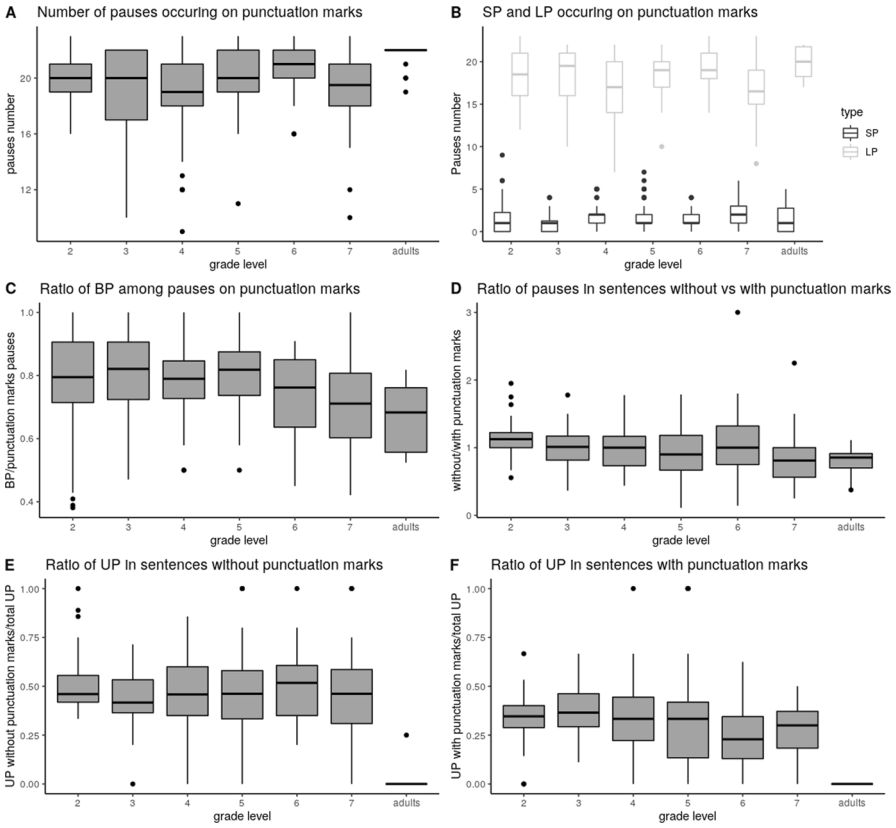

Fig. 8 Boxplots of pauses occurring at punctuation marks for readers in grades 2 to 7 and adults: number of pauses occurring at punctuation marks (**a**), number of short and long pauses occurring at punctuation marks (**b**), ratio of punctuation marks used to breathe (**c**), ratio of pauses in long sentences with and without punctuation marks (**d**), number of ungrammatical pauses (UP) occurring in long sentences with no punctuation marks (**e**) and ratio of UP occurring in sentences with punctuation marks (f)

$p = 0.002$]. However, no significant difference was observed in readers from grades 2 to 6, for whom 79% ($SD = 0.13$) used punctuation marks as cues to breathe. Seventh graders and adults, however, were less likely to breathe at punctuation marks ($M = 71\%$, $SD = 0.14$), as they took fewer breaths in general while reading aloud ($p < 0.02$). These results confirmed our initial proposal that punctuation helps young readers, from grades 2 to 5, to plan and coordinate their breathing while reading.

We then compared the number of pauses in longer sentences both with and without commas and with the same lexical complexity (Lété, Liliane, & Colé, 2004). In order to take into account the large difference in the total number of pauses made by readers ranging from second graders to adults, we computed the ratio of pauses occurring in sentences with commas versus in sentences without commas, (Fig. 8d). Grade level had a significant effect on the ratio [$\Delta\chi^2(6) = 185{,}0.55$, $p = 0.005$]. For second graders, a *t*-test showed a ratio over 1 [$M = 1.13$, $SD = 0.25$;

$t(56) = 3.68$, $p < 0.001$, $d = 0.52$]. Second graders tended to pause more frequently when reading sentences with no punctuation. For children from grades 3 to 6, the ratio decreased significantly ($p = 0.04$) and stabilized around 1. Upward from grade 7, this ratio continued to decrease ($p < 0.02$) and became significantly smaller than 1 [$t(37) = -3.161$, $p = 0.003$, $d = 0.61$]. For seventh graders and adults, pauses were more frequent in the presence of punctuation marks ($M = 0.79$, $SD = 35$). This observation effectively illustrates the inductive effect of punctuation on pausing for expert readers. For younger readers, even if they are not using all the punctuation marks to pause, punctuation may nonetheless help them to plan their pauses and avoid making ungrammatical pauses. Figure 8e, f show the ratio of ungrammatical pauses in sentences, with and without punctuation marks respectively. Due to the quasi-absence of ungrammatical pausing, adult ratios were not computed and were removed from the model testing the effect of grade level. This is the only model for which no random effects were associated with the class variable. Grade level had no impact on ungrammatical pausing in sentences without punctuation marks [$\Delta\chi^2(6) = 6.16$, $p = 0.401$]. 47% ($SD = 0.20$) of ungrammatical pauses occurred in long sentences without internal punctuation marks. On the contrary, grade level had a significant effect on ungrammatical pausing in sentences that included punctuation marks [$\Delta\chi^2(6) = 37.6$, $p < 0.001$]. For readers in primary grades, grades 2–5, 34% ($SD = 0.18$) of ungrammatical pauses occurred in sentences with punctuation marks. For middle school readers, grades 6 and 7, this ratio lowered significantly to 25% ($SD = 0.17$) ($p = 0.03$). The adult participants did not produce any grammatical pauses for either sentence type.

Taken together, these results tell us that punctuation marks are useful for placing LPs, and to a greater degree BPs, as early as grade 2. Grade level had a negligible effect on the use of punctuation. However, intra-sentential punctuation marks clearly helped children to plan pauses. Indeed, ungrammatical pauses occurred less frequently in the presence of punctuation marks. This effect was more pronounced in readers from grades 6 and 7.

Discussion

A developmental pattern of pausing acquisition

We observed that some aspects of pausing acquisition are present from the beginning of reading learning. This can be seen in bimodal pause duration distribution, breathing that almost always occurs during long pauses of which 58% are used for breathing, and punctuation marks representing 70% of long pauses that are largely used for breathing. We also found, however, that several variables developed as reading acquisition improves. Figure 9 provides an overview of the evolution of the main parameters. We were able to identify four principal stages in pausing acquisition of French readers.

- Grade 2 is characterized by numerous pauses, particularly ungrammatical pauses. Accuracy and fluency are still low and children spent a lot of time paus-

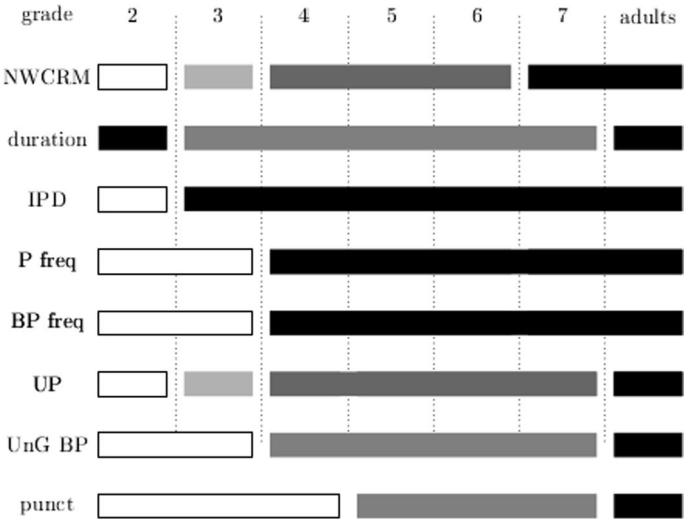

Fig. 9 Summary of the results on pausing acquisition in reading development. Black corresponds to adult-like values. Level of grey for children darkens for values closest to adults values. The parameters presented in this scheme are the number of word correctly read in a minute (NWCRM), long pause duration, inhalation to phonation delay (IPD), frequency of pauses (P nb), frequency of breathing pauses (BP freq), ungrammatical pausing (UP), ungrammatical breathing pausing (UnG BP), and number of ungrammatical pauses occurring in long sentences with punctuation (punct)

ing. As pausing patterns appear to be linked with word decoding skills, this stage involves no planning of either syntactic or respiratory pauses. Children at this age begin to rely on punctuation to help them identify appropriate pause placement and have more difficulty in the absence of punctuation. The between-participant variability is high for most of the studied parameters and reflects important differences in the progress of individual reading acquisition. Similarly, within-participant variability reflecting unstable reading rate is high.

- Grade 3 is characterized by overall fewer pauses and shorter pause duration. Coordinating linguistic content with speech breathing begins. Nevertheless, frequent ungrammatical pauses are still present at this stage and inter- and intra-variability remains high. Word decoding skills begin to improve, accuracy and reading speed increase. Thus, the increase of reading rate is obtained at the expense of pause planning.
- Grades 4–6 is characterized by breathing maturity and planning of pauses. Accuracy and reading rate are almost adult-like. The overall frequency of pauses decreases considerably, including ungrammatical pauses. Children at this stage rely more on punctuation to plan their pauses when possible. Pause patterns appear to eventually stabilize after several years, but enough errors remain at this stage to still fall short of adult-like use of pausing.
- Grade 7 is characterized by fluency and pausing patterns that are nearly adult-like. Overall planning of breathing pauses seems to be efficient while a few ungrammatical pauses still occur, and the duration of pauses are still slightly shorter than adult pauses.

To summarize, proper use of pausing patterns appears to develop alongside other reading skills. The most crucial aspect lies in the ability to consciously plan and control where these pauses occur, particularly pauses that are used for breathing. Our study showed that planning acquisition begins to develop relatively slowly during the first year of reading acquisition along with accuracy and reading rate. Noticeable progress only begins at the 4th grade level when reading skills become more automatic and children have gained enough confidence to focus more on planning instead of decoding. Pausing acquisition, therefore, is still in developmental stages at the end of primary grade level and continues through middle school. By the time children reach grade 7, pausing patterns are generally quite adult-like.

Interpretation of the main results: relation between pauses, decoding and expressivity

We observed a bimodal distribution of pause duration in adults distinguished by use of either short or long pauses, as observed by Bailly and Gouvernayre (2012) and Campione and Véronis (2002). Clearly, short and long pauses are not linked to the same linguistic functions. Short pause development seems to be less specific than long pause development. Indeed, no global tendency seems to appear in short pause analyses. In contrast, long pauses, that are more often used for breathing, develop in an interesting way. Indeed, children from grades 3 to 7 make shorter long pauses than second graders and adults. However, second graders' use of longer pauses during oral reading occurs for different reasons than adults. The most likely reason is that they are still learning to read and extended pauses cue difficulties or hesitation. Longer pauses simply give them time to perform decoding. They are speaker-oriented. As a consequence, the duration of pauses produced by very young readers is directly linked to their ability to decipher the next word, which can involve certain variability and might also lead to longer pauses (> 1000 ms). This hypothesis is supported by our observations that the pausing/reading ratio was higher in the 2nd grade than in other grades and adults.

Adults are far more likely to consciously plan their use of long pauses with certain linguistic purpose: marking major syntactic boundaries can make their reading expressive and enhance listener comprehension. They are listener-oriented. Children, even in grade 7, have not yet mastered their patterns of pausing. Once decoding is automated (here in grade 4), long pauses are used but are shorter than pauses used by adults. The variability of long pause duration is higher in adults. Their syntactic pauses are planned and used to highlight the meaning of the text and achieve greater expressiveness. This could explain the increase of within-variability of pause duration in adults. Adult readers modulate pause duration to emphasize the significance of major syntactic boundaries versus minor ones which boosts the expressiveness of their reading. In the specific context of breathing pauses, we observed that the greatest difference between second graders and adults was essentially decomposition of the breathing pauses. Adults make a long pre-inspiratory pause and a short inhalation before speaking, while second graders make a short pre-inspiratory pause and a long inhalation and post-inspiration pause. Second graders tend to breathe

when they just finish talking, leading to long inhalation to phonation delay. Adults and older children are better at planning their breathing and tend to take a breath just before they begin speaking. In summary, long pause duration can mask two different strategies: a lack of planning and decoding issues as seen in 2nd graders in contrast with the communicative use of pause location and duration for emphasizing major syntactic boundaries by expert readers. Children from grades 3 to 7 seem to fall in between the two in that they are more adept at planning their breathing than second graders but lack the modulation of pause durations observed in adult reading.

Another surprising observation was the increase of ungrammatical pausing for readers transitioning from 2nd to 3rd grade. Indeed, this increase contradicts previous studies on children describing a decrease of inappropriate pauses from grades 1–2 (Miller & Schwanenflugel, 2008) and 2 to 5 (Álvarez-Cañizo, Suárez-Coalla, & Cuetos, 2015). However, in spite of higher fluency skills, we observed that 3rd graders made more ungrammatical pauses than 2nd graders. One possible explanation for this increase could be that 3rd grade readers focus more on speed and less on accuracy, despite the fact that their pause planning is still immature. In fact, we observed a reading rate in 3rd grade similar to other children while accuracy was still significantly lower. Reading at a faster rate may then lead to less planning in pausing, and certainly breathing (Grosjean & Collins, 1979). Second graders, by contrast, read more slowly and tend to focus more on decoding, which gives them more time to plan their pauses. From grade 4, children reading rate and accuracy almost reached adult levels and these children appeared to be better at planning their pauses, both for breathing and to underline or emphasize relevant syntactic boundaries. Ungrammatical pausing tended to decrease significantly. That said, ungrammatical pauses still occurred for these readers, which may in part be due to persistent decoding difficulties (French is an opaque language and notoriously difficult to read) or analysis of complex syntactic embeddings. Moreover, beginning at the 4th grade level, punctuation begins to play a more important role in the pause planning process. Punctuation at this stage enables young readers to locate syntactic boundaries, allowing them to plan where exactly they should place their pauses.

Lung volume and speech-breathing coordination may not fully mature before age 10 (Wiechern et al., 2018). We observed, however, a mature IPD in readers as early as the 3rd grade. This suggests that children are able to plan their breathing patterns before they master syntactic pauses. Children in the 3rd grade, however, still made a number of ungrammatical breathing pauses, which is indicative of a lack of planning. To better understand this contradiction, we might consider the dynamics of pause duration. It is likely that 3rd graders reading at faster rates didn't plan their breathing pauses, but simply took breaths when they needed air, such that rapid inhalations are more closely linked to reading rate (Grosjean & Deschamps, 1975). The decrease in IPD may instead be more closely associated to "rushed" reading, and less to the capacity for planning. In grade 4, ungrammatical breathing decreased significantly in accordance with a shorter IPD, showing more mature planning of breathing pauses. This stage could indeed be related to the stage in breathing coordination observed by Hoit et al. (1990) around the age of 8. Even if speech coordination is not yet matured at this point, children rely to a certain degree on punctuation to better plan their breathing patterns while reading. The remaining ungrammatical

breathing pauses that occur in the primary grades could be explained by remaining decoding difficulties, and are likely less to do with a lack of planning but more indicative of hesitation. Indeed, young readers stopping to decipher a word or hesitate will likely make longer pauses that can then be used to breathe during the corresponding cognitive activity.

Limitations of the study

In this study, we chose to record and analyze the participants' first reading of the provided text. None of the participants, children or adults, were given the opportunity to read the text before reading it aloud. Our data reflect that readers rely on a combination of cognitive resources for understanding text syntax which facilitates making predictions to anticipate upcoming passages when reading aloud. We do acknowledge that our results would probably have been very different if the children, in particular, had been given the chance to silently read the passages provided to them beforehand. Participants' individual reading levels would, however, likely have impacted the results by showing greater differences in planning between poor readers struggling with comprehension and subsequent planning difficulties, and more advanced readers able to understand and remember the text and experience no difficulty in planning their pauses reading a familiar text. It could potentially be interesting to consider the evolution of pauses between a first reading, as we did here, and a second reading after a preliminary review of the text as preparation.

Additional types of pauses might also have been worth investigating. We did not annotate individual pause functions, apart from breathing (e.g., hesitation, syntactic, cognitive activity such as decoding or comprehension). Duration and number of pauses could potentially be linked to these pause functions. Similarly, we did not precisely identify those pauses occurring at a line break. These pauses in particular could indeed occur due to oculomotor functioning and would be less associated with conscious pause planning. Additionally, we hypothesized that these kinds of pauses could occur more frequently in young children struggling to anticipate and process a quick line return. To confirm this hypothesis, examining this data with eye-tracking support could also provide valuable insight into pause planning. Finally, we computed here the frequency of pauses related to the number of words of the text read. It could also be interesting to compute the frequency of pauses related to the amount of word pronounced. The development stages could then be different, mainly for young readers who tend to make a lot of hesitations and repetitions, leading to a number of word pronounced very different from the number of word printed.

Our group of adults were primarily teachers and PhD students, and all expert readers. Our 7th grade participants were representative of their age category in terms of fluency. Consequently, the reading level of this group, as with the other groups of children, ranged from novice (struggling) to advanced (expert). This difference of mean reading level in the adult study population may explain the slight differences between grade 7 and adults. Some children are in fact adult-like readers, while others may still struggle with reading fluency. Another fact might also have an impact on the reading levels of grade 6 and 7 students. In primary school, particularly in

grades 2 and 3, reading aloud is a daily exercise. In our adult population, reading aloud is also frequently practiced. Children in French middle school are much less likely to be asked to read aloud in the context of a classroom activities. This type of exercise is then more exceptional for most students, more so than for the other participants. This difference could have an impact on their performance, especially in their first reading of a text.

Finally, we purposefully confined our study to describing the pausing pattern. We did not consider the interplay or relationship between comprehension, fluency and pausing. The potential links between other reading skills and pausing acquisition could help to elaborate on the stages we observed in this study. For example, the pronounced within and between-participant variability in grades 2 and 3 may have resulted from differences in fluency and comprehension acquisition between children. In the same way, a longitudinal study from grades 2 to 5 could potentially be used for a more precise examination of how conscious planning of pauses develops and could reveal more about specific relationships between the different analyzed parameters. Another way of exploring pause planning linked to expressivity and comprehension would be to have listeners categorize pauses, for example, by their functions. As a matter of fact, pauses of the same duration and placement could have different functions. For example, it could be due to a cognitive activity such as deciphering versus a listener-oriented strategy to mark important boundaries in the text or reflect cognitive activities of the character in the story. These expressive functions of pauses are not directly identifiable using only acoustic markers but may be very useful in characterizing pauses planning development and its link to expressivity and comprehension.

Conclusions and perspectives

We designed our model to include several parameters of pausing (i.e., duration, number/frequency, correlation with breathing and punctuation marks) in order to characterize acquisition of expert reading pausing patterns through reading development. Our results are in-line with findings from previous studies on adults and children, but we were also able to provide new insights on reading prosody. We observed that acquisition of pause planning in our participants is organized in four stages, with a markedly rapid learning curve occurring during first years of reading learning before stabilizing toward the end of the primary grade levels and finally reaching maturity at grade 7. We also observed that punctuation marks play an important role in breathing planning and use of syntactic pauses. These observations could be particularly useful in terms of developing methods for teaching pausing planning during reading learning, for example, by emphasizing the importance of punctuation, or finding ways to help children extract syntactic structure to plan their pauses. When learning music, children are explicitly taught where and when to breathe or pause to best interpret a melody. They visualize where to pause and breathe at specific places on the textual score. We also showed that the IPD is a meaningful cue for assessing the maturation of the coordination of speech and breathing: the just-in-time air intake of adults (roughly 400 ms before phonation) give them more freedom to use

final pre-boundary lengthening and pause duration for communicative purposes. Introducing this type of structured, more systematic approach to teaching novice readers how to integrate pausing when reading aloud could help struggling readers with pause planning acquisition and reduce ungrammatical pauses that can be disruptive and prevent overall comprehension during oral reading.

Appendix 1

Mon chat est entré dans ma chambre. Il avait l'air bizarre donc j'ai tout de suite compris qu'il avait fait une énorme bêtise. D'abord j'ai pensé au poisson rouge. Je m'attendais à trouver le bocal vide. Mais mon poisson était toujours là et il me regardait de ses grands yeux ronds. Ensuite je me suis souvenu que maman avait sorti des saucisses et les avait posées sur la table. Le chat les avait volées, c'était certain. Mais dans la cuisine, les saucisses étaient toujours là, prêtes à cuire, personne n'y avait touché. Le chat est alors allé vers mon cartable. Le cartable était ouvert, tout était par terre, mon exposé déchiré en tout petits bouts. Quand j'ai vu mon travail en morceaux, je me suis senti triste, j'avais envie de pleurer. Alors le chat s'est frotté sur ma jambe, il a miaulé, il était désolé. Finalement il m'a aidé et on a préparé ensemble un bel exposé sur l'intelligence des chats.

Acknowledgements We thank the school teachers and pupils for welcoming Erika Godde and Manon Metz and wearing respiratory belts. Anne-Claire Dugué recorded the adult readers. Margaux Manka, Anne-Laure Piat-Marchand and Camille Deshayes patiently corrected numerous phonetic alignment

Funding This research has been conducted as part of "Fluence", an e-FRAN project founded by the "Investissement d'Avenir" program handled by the French "Caisse des dépôts".

Availability of data and material Data are available on Open Science Framework.

Code availability Not applicable.

Declarations

Conflict of interest The authors declares that they have no conflict of interest statement.

Ethics approval This research has been approved by the ethic committee of Université Grenoble Alpes. The ethic comittee approval number is CERNI-Avis-2018-03-06-2.

Consent to participate We collected the consent to participate for all participants and the authorization of parents for minor participants.

Consent for publication We collected the consent for results publication for all participants and the authorization of parents for minor participants.

References

Álvarez-Cañizo, M., Suárez-Coalla, P., & Cuetos, F. (2015). The role of reading fluency in children's text comprehension. *Frontiers in Psychology, 6*, 1810. https://doi.org/10.3389/fpsyg.2015.01810

Álvarez-Cañizo, M., Suárez-Coalla, P., & Cuetos, F. (2018). Reading prosody development in Spanish children. *Reading and Writing: An Interdisciplinary Journal, 31*, 35–52. https://doi.org/10.1007/s11145-017-9768-7

Arcand, M.-S., Dion, E., Lemire-Théberge, L., Guay, M.-H., Barrette, A., Gagnon, V., Caron, P.-O., & Fuchs, D. (2014). Segmenting texts into meaningful word groups: Beginning Readers' prosody and comprehension. *Scientific Studies of Reading, 18*, 208–223. https://doi.org/10.1080/10888438.2013.864658

Bailly, G., & Gouvernayre, C. (2012). Pauses and respiratory markers of the structure of book reading. In *Annual conference of the international speech communication association 2012* (pp. 2218–2221). https://hal.archives-ouvertes.fr/hal-00741667.

Bates, D., Mächler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software, 67*(1), 1–48.

Benaglia, T., Chauveau, D., Hunter, D. R., & Young, D. (2009). Mixtools: An R package for analyzing finite mixture models. *Journal of Statistical Software, 32*(6), 29.

Benjamin, R. G., & Schwanenflugel, P. J. (2010). Text complexity and oral reading prosody in young readers. *Reading Research Quarterly, 45*, 388–404. https://doi.org/10.1598/RRQ.45.4.2

Boersma, P., & Weenink, D. (2020). Praat: Doing phonetics by computer [computer program]. http://www.praat.org.

Boliek, C. A., Hixon, T. J., Watson, P. J., & Jones, P. B. (2009). Refinement of speech breathing in healthy 4-to 6-year-old children. *Journal of Speech, Language, and Hearing Research, 52*, 990–1007. https://doi.org/10.1044/1092-4388(2009/07-0214)

Brennan, S. E., & Williams, M. (1995). The feeling of anothers knowing: Prosody and filled pauses as cues to listeners about the metacognitive states of speakers. *Journal of Memory and Language, 34*, 383–398. https://doi.org/10.1006/jmla.1995.1017

Breznitz, Z. (1990). Vocalization and pauses in fast-paced reading. *The Journal of General Psychology, 117*(2), 153–159. https://doi.org/10.1080/00221309.1990.9921132

Campione, E., & Véronis, J. (2002). A large-scale multilingual study of silent pause duration. *Speech Prosody, 2002*, 99–102.

Campione, E., Véronis, J., & Delic, E. (2002). Étude des relations entre pauses et ponctuations pour la synthèse de la parole à partir de texte (Study of relationships between pauses and punctuation for speech synthesis from text). In ATALA *Traitement Automatique des Langues Naturelles 2002 (TALN)*. AFCP. http://www.afcp-parole.org/doc/Archives_JEP/2002_XXIVe_JEP_Nancy/talnrecital/TALN/actes_taln/articles/TALN16.pdf.

Friot B (2007) *Histoires pressées.* Milan.

Godde, E., Bosse, M.-L., & Bailly, G. (2021). Echelle Multidimensionnelle de Fluence: nouvel outil d'évaluation de la fluence en lecture prenant en compte la prosodie, étalonné du CE1 à la 5e (Echelle Multidimensionnelle de Fluence: A new tool to assess reading fluency including prosody in french, calibrated for grade 2 to 5). *L'Année Psychologique, 121*(2), 19–43.

Godde, E., Bosse, M.-L., & Bailly, G. (2020). A review of reading prosody acquisition and development. *Reading and Writing: An Interdisciplinary Journal, 33*, 399–426. https://doi.org/10.1007/s11145-019-09968-1

Goldman, J.-P., François, T., Roekhaut, S., & Simon, A. C. (2010). Étude statistique de la durée pausale dans différents styles de parole (Statistical study of pauses duration in various speech styles). *Journées d'Etude sur la Parole 2010 (JEP)*, 161–164. http://hdl.handle.net/2078.1/81909.

Grosjean, F., & Collins, M. (1979). Breathing, pausing and reading. *Phonetica, 36*(2), 98–114. https://doi.org/10.1159/000259950

Grosjean, F., & Deschamps, A. (1975). Analyse contrastive des variables temporelles de l'anglais et du français: vitesse de parole et variables composantes, phénomènes d'hésitation (A contrastive analysis of temporal variables in french and english : speech rate and variable component, hesitation process). *Phonetica, 31*, 144–184. https://doi.org/10.1159/000259667

Grosman, I., Simon, A. C., & Degand, L. (2018). Variation de la durée des pauses silencieuses: impact de la syntaxe, du style de parole et des disfluences (Variation of silent pauses duration : effect of syntax, speech style and disfluences). *Langages, 211*(3), 13–40. https://doi.org/10.3917/lang.211.0013

Hoit, J. D., Hixon, T. J., Watson, P. J., & Morgan, W. J. (1990). Speech breathing in children and adolescents. *Journal of Speech, Language, and Hearing Research, 33*(1), 51–69. https://doi.org/10.1044/jshr.3301.51

Kentner, G., & Vasishth, S. (2016). Prosodic focus marking in silent reading: Effect of discourse, context and rhythm. *Frontiers in Psychology*, *7*, 1–19. https://doi.org/10.3389/fpsyg.2016.00319.

Kuhn, M. R., Schwanenflugel, P. J., & Meisinger, E. B. (2010). Aligning theory and assessment of reading fluency: Automaticity, prosody, and definitions of fluency. *Reading Research Quarterly, 45*, 230–251. https://doi.org/10.1598/RRQ.45.2.4

Lalain, M., Espesser, R., Ghio, A., De Looze, C., Reis, C., & Mendonca-Alves, L. (2014). Prosodie et lecture: particularités temporelles et mélodiques de l'enfant dyslexique en lecture et en narration (Prosody and reading: temporal and melodic specificities of dyskexic children in reading and narration). *Revue de Laryngologie Otologie Rhinologie*, *135*, 71–82. https://hal.archives-ouvertes.fr/hal-01485957.

Lalain, M., Legou, T., Fauth, C., Hirsch, F., & Didirkova, I. (2016). Que disent nos silences? apport des données acoustiques, articulatoires et physiologiques pour l'étude des pauses silencieuses (What do our silences say? Contribution of acoustic, articulatory and physiological data to silent pauses study). *JEP-TALN-RECITAL 2016*, *1*, 563–570. https://hal.archives-ouvertes.fr/hal-01462180.

Lété, B., Liliane, S.-C., & Colé, P. (2004). Manulex: A grade-level lexical database from french elementary-school readers. *Behavior Research Methods, Instruments, andComputers, 36*, 156–166. https://doi.org/10.3758/BF03195560

Maeder, C., Roustit, J., Launay, L., & Touzin, M. (2018). *Evaleo 6–15*. Orthoéditions.

Martin, P. (2011). Ponctuation et structure prosodique (Punctuation and prosodic structure). *Langue Française, 172*, 99–114. https://doi.org/10.3917/lf.172.0099

Miller, J., & Schwanenflugel, P. J. (2006). Prosody of syntactically complex sentences in the oral reading of young children. *Journal of Educational Psychology, 98*, 839–853. https://doi.org/10.1037/0022-0663.98.4.839

Miller, J., & Schwanenflugel, P. J. (2008). A longitudinal study of the development of reading prosody as a dimension of oral reading fluency in early elementary school children. *Reading Research Quarterly, 43*, 336–354. https://doi.org/10.1598/RRQ.43.4.2

Molomer, S. D., Trausan-Matu, S., Dessus, P., & Bianco, M. (2015). Analyzing students pauses during reading and explaining a story. *RoEduNet International Conference-Networking in Education and Research (RoEduNet NER), 15*, 90–93. https://doi.org/10.1109/RoEduNet.2015.7311974

Raven, J. (2003). Raven progressive matrices. In R. S. McCallum (Ed.), *Handbook of nonverbal assessment* (pp. 223–237). Berlin: Springer. https://doi.org/10.1007/978-1-4615-0153-4_11

Rochet-Capellan, A., Bailly, G., & Fuchs, S. (2014). Is breathing sensitive to the communication partner? *Speech Prosody, 204*, 613–617.

Samuels, S. J., & Flor, R. F. (1997). The importance of automaticity for developing expertise in reading. *Reading and Writing Quarterly: Overcoming Learning Difficulties, 13*, 107–121. https://doi.org/10.1080/1057356970130202

Schwanenflugel, P. J., Hamilton, A. M., Kuhn, M. R., Wisenbaker, J. M., & Stahl, S. A. (2004). Becoming a fluent reader: Reading skill and prosodic features in the oral reading of young readers. *Journal of Educational Psychology, 96*, 119–129. https://doi.org/10.1037/0022-0663.96.1.119

Team, R. (2019). R: A language and environment for statistical computing. R foundation for statistical computing. https://www.r-project.org/.

Wang, Y.-T., Green, J. R., Nip, I. S., Kent, R. D., & Kent, J. F. (2010). Breath group analysis for reading and spontaneous speech in healthy adults. *Folia Phoniatrica Et Logopaedica, 62*, 297–302. https://doi.org/10.1159/000316976

Wiechern, B., Liberty, K. A., Pattemore, P., & Lin, E. (2018). Effects of asthma on breathing during reading aloud. *Speech, Language and Hearing, 21*(1), 30–40. https://doi.org/10.1080/2050571X.2017.1322740

Wlodarczak, M., & Heldner, M. (2017). Respiratory constraints in verbal and non-verbal communication. *Frontiers in Psychology, 8*, 708. https://doi.org/10.3389/fpsyg.2017.00708