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Pausing and Breathing while Reading Aloud : Development from 2nd to 7th grade

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Pausing and Breathing while Reading Aloud:

Development from 2nd to 7th grade

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Abstract

Pauses when reading aloud play an essential role in reading and listening comprehension. Among the various types of pauses, breathing pauses during oral reading are particularly essential. 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 younger French speaking learners ranging from second to seventh graders to adults. Voice and breathing patterns of 295 children and 20 adults were recorded during oral reading. Specific focus was given to the frequency, duration and placement of breathing pauses and inhalation to phonation delay. Our results revealed that the youngest students took 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 the adult level. This developmental study suggests that children's acquisition of pausing patterns during oral reading can effectively be described in four steps that occur between the 2nd and 7th grades, and highlights the important role punctuation plays in planning breathing pauses and syntactic-prosodic breaks.

Keywords: reading prosody, breathing-voice coordination, reading development, pausing in reading

Introduction

Reading aloud involves numerous complex cognitive processes: letter recognition, grapheme-phoneme mapping, semantic retrieval, syntactic extraction, articulatory planning, etc. An important part of children's reading acquisition process involves learning to coordinate of all these processes. In the first years of reading acquisition, teachers focus primarily on skills involving automation of word decoding. Once a young learner's decoding skills become more automatic, their cognitive resources can be freed for other purposes such as developing comprehension. The ability to add prosodic breaks during oral reading of a given text requires engaging further cognitive resources. To read with adequate prosody, the reader must add appropriate intonation and plan pauses to effectively match the syntax and the meaning of the text (Kuhn et al., 2010). In speech, pauses play an essential role in defining the communication purpose. They not only highlight the syntax of the discourse but allow the listener to understand meaning. The specific nature of pauses 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, their duration and frequency have been shown to be closely linked to text comprehension (Molomer et al., 2015; Arcand et al., 2014, in French). Lalain et al. (2016) proposed that, although silent, pauses can be an integral part of the message being conveyed and merit close attention. The present study aims to fill the gap of knowledge about the development of reading pauses in French children.

Pausing in adults

In adults, pauses have been studied in different oral modalities, for example in reading and in spontaneous speech that lead to different pause configuration (Goldman et al., 2010). Several authors showed a multimodal distribution of pause duration in several languages. Campione and Véronis (2002) showed a bimodality of pause duration in text reading, brief pauses (< 200ms) and medium pauses (200-1000ms), in five languages (French, German, English, Italian and Spanish). Pauses longer than 1000ms were only present in spontaneous speech. Goldman et al. (2010) also found a bimodal distribution of pauses in text reading, with short pauses around 100ms and longer ones measuring roughly 500ms. Bailly and Gouvernayre (2012) found that a French expert reader reading an audio book made short pauses (< 200msec) and three kinds of long pauses classified according to their location: sentence internal pauses (occuring at major syntactic boundaries or punctuation), end of sentence pauses and end of paragraph pauses. Lalain et al. (2014; see also Grosjean & Deschamps, 1975) classified pauses into three main categories according to their uses: syntactic pauses highlighting text comprehension, hesitation pauses revealing a high cognitive load, and physiological pauses that are mainly respiratory. Grosman et al. (2018) also

linked the characteristics of pause patterns (i.e., duration and placement) to their discursive functions. This mapping depends mostly on the type of speech. In reading aloud, they observed two modes: short pauses linked to articulation processes and long pauses linked to cognitive processes: hesitation, syntactic and physiological. These authors focused their analysis on each category of long pauses considered separately rather than mean measures or overall pause occurrence. However, 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). These are long syntactic pauses often used by the reader to breathe. Pauses have also been shown to be longer when they occur between particularly long sentences or longer phrases than for shorter sentences (Zvonik & Cummins, 2003). Pausing patterns in adult reading has also been closely linked to the text punctuation (Martin, 2011; Campione et al., 2002).

Pausing in children reading

With mostly syntactic pausing at major boundaries and punctuation, adult pausing patterns rely on precise planning and online processing of the syntactical structure. Prosodic planning is considered a reliable marker of reading fluency and overall reading skills (Cowie et al., 2002; Benjamin et al., 2013) and is clearly linked to written comprehension (e.g., Álvarez-Cañizo et al., 2015; Arcand et al., 2014; Schwanenflugel et al., 2004; Miller & Schwanenflugel, 2006;). Children, on the other hand, appear to use pauses to aid their comprehension when reading difficult texts (Benjamin and Schwanenflugel, 2010) and may serve as an additional tool to enhance their online comprehension abilities. However, pauses planning is rarely explicitly taught to children when they are learning to read. To date, very few studies have investigated the development in younger learners of adult level pausing in reading (Godde et al., 2020, for a review). Studies in English (Schwanenflugel et al., 2004; Miller & Schwanenflugel, 2006) and Spanish (Álvarez-Cañizo et al., 2017) 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 reading fluency and comprehension. Pausal intrusions, also called ungrammatical pauses, are intra-sentential pause patterns occurring at syntactic boundaries, for example, between a noun and its specifier or adjective, after a preposition or inside a word. This type of pause is very frequently observed in young readers and tends to decrease rapidly from grade 1 to grade 3. Third graders, however, tend to produce more intra-sentential pauses and within-word pauses than adults (Álvarez-Cañizo et al., 2017). Pause frequency and their duration, both inter and intra-sentential, also decrease rapidly from grade 1 to grade 3, but still do not reach adult level at the end of the primary grade. Moreover, pausing patterns in oral reading depend on the individual's reading skill level: compared to fluent readers in the same grade, non-fluent readers tend to make more frequent and longer pauses, and produce more ungrammatical pauses (Godde et al., 2020). As Grosjean and Collins (1979) reported in their

study of pausing in adults, Breznitz (1990) showed that pausing patterns are also at least partially dependent on reading speed. Increased reading speeds in children corresponded to fewer and shorter pauses. Additionally, young children appear to rely more heavily on punctuation to plan their pauses than older, more experienced readers. Miller and Schwanenflugel (2008) proposed that this may be due to a decrease of motivation to use punctuation as reading skills improve. 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.

Pausing and breathing in 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 balance 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 et al., 2010). There seems to be no adaptation of the syntactic structure to the breathing needs. Breathing pauses, however, can be longer and less grammatical when the speaker hesitates. The cognitive load then increases and the syntax is less structured: consequently, anticipation on the next utterance becomes more difficult. Hesitation pauses are more often present during spontaneous speech when the discourse is less constrained than during oral reading and are almost non-existent in adult level reading, with less than 2% of inappropriate breathing pauses (Wang et al., 2010).

In oral reading, the structure is constrained by the text. 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 cues of the text structure, supporting the importance of planning breathing pauses in reading. Grosjean and Collins (1979) showed that high reading speed has an impact on breathing while reading. 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. According to Grosjean and Collins (1979), in reading measured at a standard rate, breathing patterns will be more dependent on preplanned pause patterns. But 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 balance between the need to breath and respecting 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 visual cues to help place their inspiration during syntactic pauses. 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. As the number of syllables pronounced in one exhalation gradually increases, the level of difficulty coordinating breath inspiration with linguistic or communicative purpose decreases (Boliek et al., 2009). It has also been shown that a boost in progress tends to occur between the ages 7 and 8 years (Hoit et al., 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 controlled breathing patterns in reading. Among the few studies that have investigated this aspect of oral reading, one study focused on children with and without asthma (Wiechern et al., 2018) while another study children with and without dyslexia (Lalain et al., 2014). For control children, these selected studies were only able to show that fewer but longer breathing pauses were produced during the reading of difficult text. 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 duration and its eventual multimodality, as observed in adults and anticipated that this would reveal two separate modalities, short and long pauses, that develop in parallel with reading acquisition. Secondly, we focused on the number or frequency of pauses. According to literature, 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 pausal would be adult-like for pupils at who reached primary school age. Thirdly, we concentrated specifically on breathing pauses spotted by the use of two respiratory belts: their frequency, duration and their planning through the inhalation to phonation delay. Our hypothesis here was that the number of breathing pauses would decrease up to the end of primary grades when breathing patterns mature. 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 breath than older children and adults, particularly when navigating longer, more complex sentences.

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 representative 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 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 excluded. 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 et al., 2018) and their non-verbal reasoning level measured with the PM38 test (Raven et al., 2003). Both scores are congruent with the children's age according to established standards.

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.

Table 1: Characteristics of the participants according to their grade level: means (standard deviations). Age is expressed in years:months. CWPM = number of words correctly read per minute.

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
PM38 raw score	33.6(9)	37.5(8)	39.7(6.8)	43.7(6.8)	38.6(5.9)	41.5(6.3)	NA

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 to help distinguish phrases within the sentence. The average lexical frequencies of both long sentence types are equivalent (Lété et al., 2004), 4,528 occurrences for a million word (SD = 325) for the sentences with punctuation marks and 4,406 occurrences for a million words (SD = 340) for the others. The text is presented in Appendix 1.

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 pre-schooler". This instruction was intended to (1) encourage an expressive reading and (2) to be ensure that it would be understood by the youngest readers. 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. Amplifier and belts signals were acquired with a Biopac MP150 to synchronise voice and breathing recordings. The headset microphone allowed to capture the breathing sound during the vocalization.

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, 2020). At the end of this process, the pronunciation database contained 1,241 correct and 1,111 incorrect pronunciations of the 174 words contained in the text, including 67 correct and 15 incorrect pronunciations comprising internal pauses, some of which were breathing pauses.

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 Figure 1. Lastly, we computed 16,895 pauses from the 315 total readings, among which 8,900 were annotated as breathing pauses.

Data Analyses

For each participant, various parameters concerning pauses duration (mean duration, within-participant variability) and pauses frequency, number of pauses per word of text (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).

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 et al., 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 > .05), except for one. For each parameter, we compared the empty model and the model with the grade level as a fixed factor, using ANOVA. We then reported the significance of grade level with $\Delta\chi2$(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 only 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 reported the mean and the standard deviation of the cluster.

Results

Pause duration

Figure2 shows the distribution of log duration of pauses for each level. A Shapiro-Wilk test showed that, at each level, pauses duration is significantly different from the normality ($p < .001$ for each level). In accordance with previous studies (Campione et al., 2002; Goldman et al., 2010; Bailly & Gouvernayre, 2012), the distribution appeared bimodal at every level. We approximated the bimodal distributions using Gaussian Mixture Model with the normalmixEM function of the mixtools package (Benaglia et al., 2009). The models converged for each level. The parameters calculated for each approximation are presented in Table 2 and plotted on Figure 2.

As our data were fitted with bimodal distributions as recommended by Campione and Véronis (2002), a distinction was made between short pauses (SP) centerd around the first gaussian (on average around 125ms) and long pauses (LP) centerd around the second gaussian (on average around 470ms). 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 congruent with those of Campione and Véronis (2002) and Bailly and Gouvernayre (2012).

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

We then looked at the effect of the grade level on pause duration. The grade level had a significant effect on both SP ($\Delta\chi^2(6) = 40.5$, $p < .001$) and LP ($\Delta\chi^2(6) = 28.7$, $p < .001$) mean duration. Overall, pause duration tended to decrease with grade and to be longer for adults than for the oldest children (see Figure 1 A and B). More precisely, the Tukey test on SP showed that 2nd graders, 4th graders and adults produced significantly longer SP (M = 151ms, SD = 14) than the 3rd, 5th and 6th graders (M = 136ms, SD = 13; $p < .001$). Seventh graders produced significantly shorter SPs (M = 130ms, SD = 10) than any other group ($p < .029$). The Tukey test on LP revealed that 2nd graders and adults had significantly longer LPs (M = 630ms, SD = 117) than children in grades 3 to 7 (from grade 3 to 7: M = 528ms, SD = 103; $p < .001$).

The effect of grade level is also significant on the within-participant variability (i.e., standard deviation). For SP duration (see Figure 3C; $\Delta\chi^2(6) = 37.5$, $p < .001$), the grade effect seemed to follow the same pattern for variability than for duration: 2nd graders, 4th graders and adults produced less regular SPs than children in in higher grades. The grade level also had a significant effect on within-participant variability of LP duration (see Figure 3D; $\Delta\chi^2(6) = 30.9$, $p < .001$), essentially due to the high variability of LP duration observed among second graders (M = 373ms, SD = 135) compared to other grade levels and adults ($p < .024$). This effect might be explained by the fact that the youngest readers made numerous hesitation pauses. Older children produced more regular LPs. It is also worth noting that the adults presented significantly more variation in their LP duration (M = 293, SD = 94) than children between grades 4 and 7 (M = 244, SD = 102; $p < 0.04$).

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 duration. Grade level showed to have a significant effect on the frequency of both SPs ($\Delta\chi^2(6) = 28{,}79$ $p < .001$) and LPs ($\Delta\chi^2(6) = 35.83$ $p < .001$). The overall amount of SPs and LPs decreased with grade level (see Figure4A and 4B). More precisely, the Tukey tests showed that second graders produced SPs more frequently (M = 0.09, SD = 0.04) than all other participant ($p < .001$). From grade 3 to 7, there was no significant difference between grade levels (M = 0.05, SD = 0.03). The developmental pattern of LPs appeared to

differ slightly. Second and third graders made significantly more LPs (M = 0.36, SD = 0.20) than both the older children and adults ($p < .001$). The frequency of LPs remained stable for students in grades 4 to 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 4 (SD < 08). This observation confirms the degree of variability of reading skills in the first year of reading learning. Grade level also had a significant effect on the ratio of SPs versus LPs (see Figure 4C; $\Delta\chi^2(6) = 29.79$, $p < .001$). Adults made significantly more short pauses (M = 0.37, SD = 0.17) than children ($p < .014$).

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 in a word. Our results showed that grade level was strongly correlated to UP frequency (see Figure 4D; $\Delta\chi^2(6) = 33.5$, $p < .001$). The frequency of UPs made by second and third graders (M = 0.18, SD = 0.15) was roughly three times higher ($p < .001$) than in the other children. These pauses then dramatically decreased in fourth graders and stabilize in children in grades 5 to 7 (M = 0.06 , SD = 0.05; $p < .003$).In adults, UP's frequency is close to zero. Importantly, adults did produce UPs. Indeed, our recordings of the participants' first readings of the text revealed that decoding difficulties did occur for some adults. We also looked at the ratio of ungrammatical pauses among all the pauses (see Figure 4E). Grade level had a significant impact on this ratio ($\Delta\chi^2(6) = 37.7$, $p < .001$). Although we expected the ratio to decrease from grades 2 to grade 4 and then stabilize with the acquisition of automaticity, our data showed a significantly higher ratio in third graders (M = .44, SD = .18) compared to second graders (M = .32, SD = .13; $p < .001$). The ratio decreased in fourth graders (M = .29, SD = 14; $p < .001$) and appeared to stabilize in children from grades 5 to 7 (M = .20, SD = .13). However, it remained higher than the ratio we observed in adults (M = .06, SD = .03; $p < .001$). What stood out was that the ratio was not yet adult-like in seventh graders. Variability in UP frequency between participants was particularly high in second and third graders (respectively, SD = .13 and .18). Once again, this could be due to the variability of reading skills during the first years of reading acquisition.

To sum up, SP and LP frequency decreased and seemed to level off in children from grades 4. The number of LPs produced by seventh graders is adult-like but they produced fewer SPs than the adults in this study. Our results show that ungrammatical pauses occurred often in the initial years of reading acquisition and were used more frequently by seventh graders than the adult readers. Pause planning seemed fairly efficient in children from grades 4.

Breathing pauses (BPs)

Our first consideration here was looking 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 8,900 BPs analysed, only 15 were classified as SPs. 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 Figure 5B; $\Delta\chi^2(6) = 9.95$, $p = .12$) which was around 58% (SD = .13) of the overall number of pauses. Grade level, however, appeared to have a significant effect on BP frequency ($\Delta\chi^2(6) = 37.6$, $p < .001$). BPs decreased rather dramatically in children from grades 2 to grade 7 and adults (see Figure 5A). Grade 2 children made significantly more BPs (M = 0.26, SD = 0.10) that children from grade 4 and adults ($p < .001$), which we also observed in the third graders (M = 0.20, SD = 0.10; $p < .05$). The number of BPs levelled off from grades 4 to 7 and adults (M = 0.12, SD = 0.04)).

Grade level also had a significant effect on BP duration ($\Delta\chi^2(6) = 23.7$, $p < .001$). 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) were significantly longer ($p < .022$) than BP duration in children from grades 3 to 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 showed to have a significant effect on IPD ($\Delta\chi^2(6) = 23.7$, $p < .001$). In second graders, IPD was significantly higher (M = 529, SD = 117; $p < .001$) than in children from the other grades and adults (MD = 413, SD = 110). This indicated to us that 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 before beginning to speak and exhibited normal duration IPD of around 400ms (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 appeared to have near adult-like planning of their BPs. As for LP duration, the IPD and BP internal duration variability in each subject is affected by grade level (IPD: $\Delta\chi^2(6) = 42.7$, $p < .001$; BP: $\Delta\chi^2(6) = 29.9$, $p < .001$). The pattern was the same for both 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 fit the syntax and be grammatical. As expected, the grade level had an impact on the frequency of UBPs ($\Delta\chi^2(6) = 32.3$, $p < .001$). Children in grades 2 and 3 made significantly more UBP pauses (M = 0.08, SD = 0.06) than the others ($p < .001$). The number of UBP was divided by three in the case of fourth graders (M = 0.03, SD = 0.04; $p < .02$). It then levelled off in children from garde 5 to grade 7 (M = 0.02, SD = 0.02). In adults, the number of UBPs was null, effectively confirming that 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 showed to have a significant effect ($\Delta\chi^2(6) = 36.7$, $p < .001$). This ratio was significantly higher in children from grades 2 and 3 (M = 29%, SD = .16) than for older children (M = 18% in fourth grade, $p < .001$). 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 develop in parallel with reading skills (e.g., matching decreases of UP and IPD), and lung development (e.g., decrease of pauses number). Children seem to acquire breathing-reading coordination around the grade 4 level. However, while BP planning is observable starting at grade 4, this skill is still not adult-like by the age of grade 7.

Punctuation effect on pausing patterns

As previously reported by Martin (2011), punctuation marks in written language are important signals that tell the reader when prosody is required. In this study, we examined how children use punctuation to calibrate 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 began by looking 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 Figure 6A, 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 ($\Delta\chi^2(6) = 20.7$, $p = .002$). 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) ($p < .001$), more commonly commas. We then took a closer look at the types of pauses occurring at punctuation marks (see Figures 6B and 6C). 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 ($\Delta\chi^2(6) = 20.7$, $p = .002$). However, no significant difference was observed in readers from grades 2 to 6, for whom 79% (SD = .13) used punctuation marks as cues to breathe. Seventh graders and adults, however, were less likely to breathe at punctuation marks (M = 71%, SD = .14), as they took fewer breaths in general while reading aloud ($p < .02$). These results confirmed our initial proposal that punctuation serves as a useful aid to help young readers plan and coordinate their breathing while reading.

We then proceeded to compare the number of pauses in longer sentences both with and without commas and with the same lexical complexity (Lété et al., 2004). 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, (Figure 6D). Grade level had a significant effect on the ratio ($\Delta\chi^2(6) = 18.55$, $p = .005$). For second graders, a t-test showed a ratio over 1 (M = 1.13, SD = 0.25; $t(56) = 3.68$, $p < .001$, $d = 0.52$). Second graders tended to pause more frequently when reading sentences with no punctuation. For children from grades 3 to 6, the ratio decreased significantly ($p = .04$) and stabilized around 1. Upward from grade 7, this ratio continued to decrease ($p < .02$) and became significantly smaller than 1 ($t(37) = -3.161$, $p = .003$, $d = 0.61$). For seventh graders and adults, pauses were more frequent in the presence of punctuation marks (M = .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. Figures 6E and 6F 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 ($\Delta\chi^2(6) = 6.16$, $p = .401$). Forty-seven percent (SD = .20) of ungrammatical pauses occurred in long sentences with no help of punctuation marks. On the contrary, grade level had a significant effect on ungrammatical pausing in sentences that included punctuation marks ($\Delta\chi^2(6) = 37.6$, $p < .001$). For readers in primary grades, grades 2 to 5, 34% (SD = .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 = .17) ($p = .03$). The adult participants made no grammatical pauses for either type of sentence.

Taken together, these results tell us that punctuation marks are used for LPs, mostly BPs, and occur as early as grade 2. Grade level appeared to have only a negligible effect, likely due to lung maturation. However, intra-sentential punctuation marks clearly helped children to plan pauses. When children readers were successful with decoding, ungrammatical pauses occurred less frequently in the presence of punctuation marks. This effect was more pronounced in readers at the middle school level.

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 advanced. Figure 7 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. As pausing patterns appear to be closely 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 reflect important differences in rates 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 elevated. Word decoding skills begin to improve, which leads to increased reading rates at the expense of pause planning.

- **Grades 4-6** is characterized by breathing maturity and planning of pauses. 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 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 control, or plan, 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. More noticeable progress really 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. 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 it does for adults. The most likely reason is that they are still learning to read and extended pauses represent difficulties or hesitation. Longer pauses simply give them time to think about decoding, which is to say they engage in a cognitive activity. As a consequence, the duration of pauses made by very young readers is linked directly to the level of their ability to decipher the next word, which can involve certain variability and might also lead to longer pauses (> 1000 ms).

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. Children, even in grade 7, have not yet mastered their patterns of pausing. Once decoding is automated (around grade 3), long pauses are used but are less pronounced than pauses used by adults. Consequently, 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 may play more with pauses 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 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 and a will to emphasize major syntactic boundaries with long pauses for 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 use of emphasis more common in adult reading.

Another interesting observation is the increase of ungrammatical pausing for readers transitioning from 2nd to 3rd grade. Indeed, a previous study on children described a decrease of inappropriate pauses from grades 1 to 2 (Miller & Schwanenflugel, 2008) and 2 to 5 (Álvarez-Cañizo et al., 2015). However, in spite of higher fluency skills1, 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 they pause planning is still immature. Reading at a faster rate leads to less planning in pausing, and certainly breathing (Grosjean & Collins, 1979). Second graders, by contrast, are less confident decoding, read more slowly and tend to focus more on decoding, which gives them more time to plan their pauses. From grade 4, children seem to be more able to plan their pauses, both for breathing and to underline relevant syntactic boundaries, and ungrammatical pausing tends to decrease significantly. That said, ungrammatical pauses still occur for these readers, most likely due to decoding issues and lack of complex syntax anticipation. 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 visualize syntactic boundaries, allowing them to plan where exactly they should place their pauses.

In terms of lung and coordination maturation, breathing coordination may not fully mature before age 10 (Wiechern et al., 2018). We observed, however, a mature inhalation-to-phonation delay 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 more

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 were more closely linked to reading rate (Grosjean & Deschamps, 1975). The decrease in inhalation to phonation delay 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 inhalation-to-phonation delay, 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 analyse the participants' first reading of the provided text. None of the participants, children and adults, were given the opportunity to read the text before reading it aloud. Our data reflect then the online treatment of the text's syntax and the anticipation in reading aloud. Our results would probably have been very different if the children had the occasion to silently read the text 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, 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, these kinds of pauses could occur more frequently in young children struggling to anticipate and process a quick line return. 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 word 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 each expert reader. 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 achievement, 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 analysed parameters.

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 largely correspond 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 happened 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 music score. 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.

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Conflict of interest Not applicable

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

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

Code availability Not applicable

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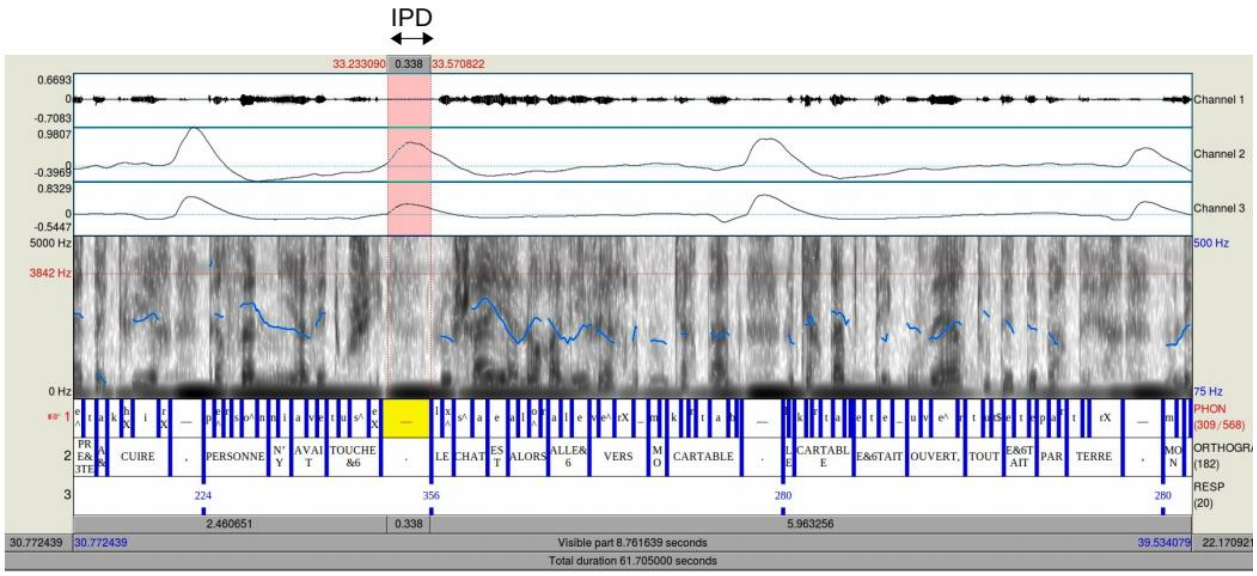

Figure 1: Praat screenshot showing audio signal on channel one, respiratory belt signals on channel 2 (abdominal) and 3 (thoracic) and annotations of phonemes and pauses, words and inhalation to phonation delay (IPD). IPD was measured manually using audio and belts signals

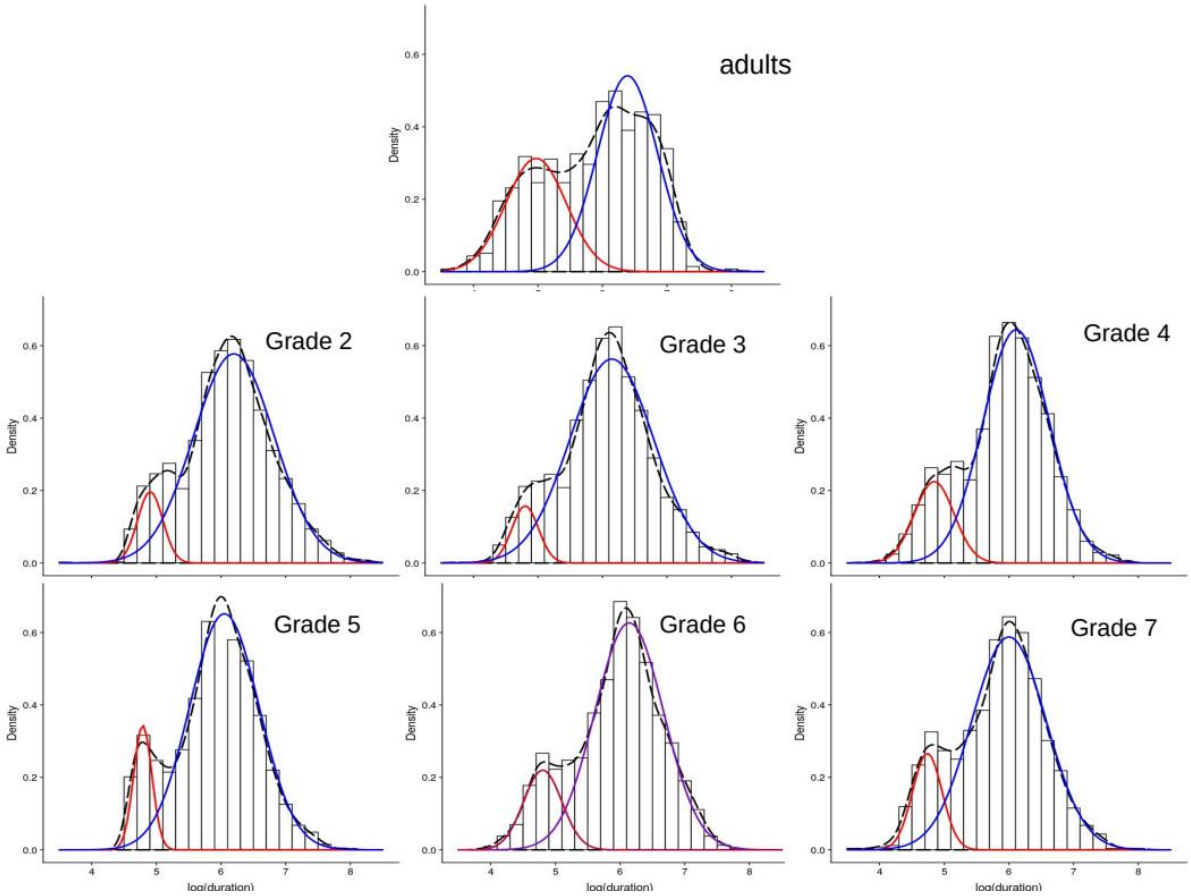

Figure 2: Distribution of log duration pauses for each grade level: histograms and density curves (dashed line). Distributions have been approximated using a mixture model of two gaussians (short pauses = red line, long pauses = blue line)

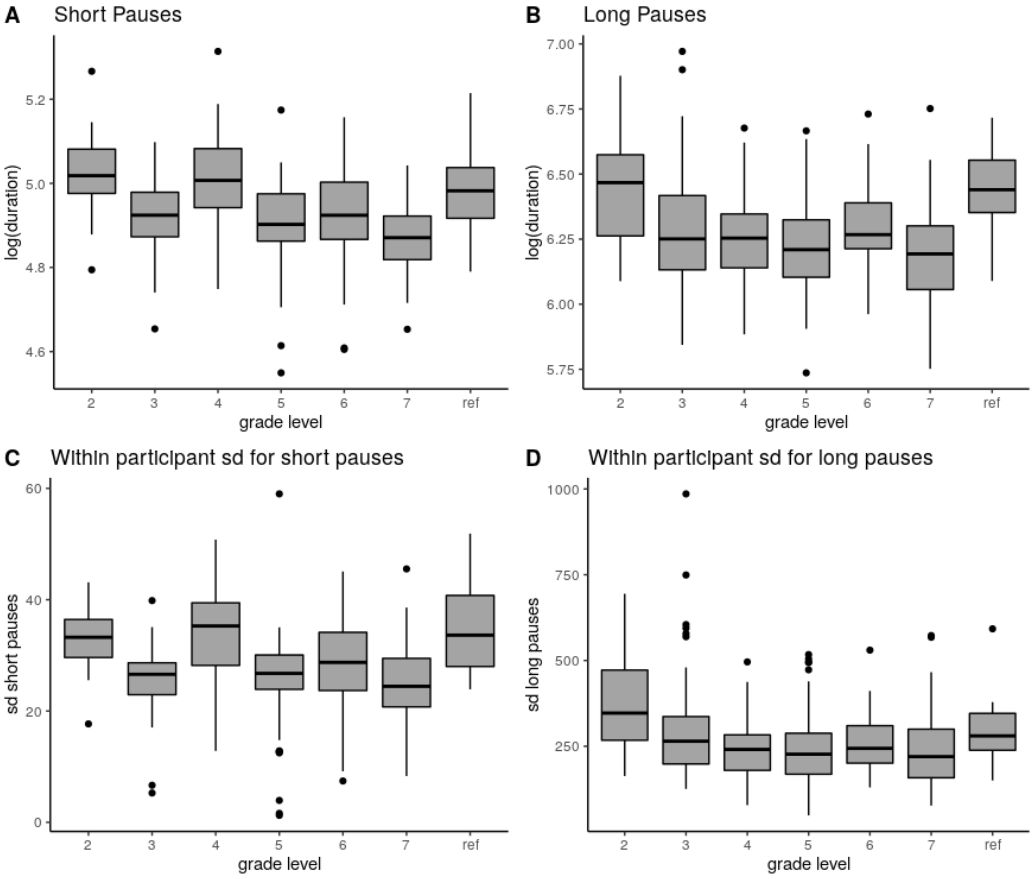

Figure 3 : Boxplots of pause durations corresponding to grade level, for short pauses (SP) in A and long pauses (LP) in B. Evolution of within-participant variability (standard deviation) according to grade level for SP in C and LP in D

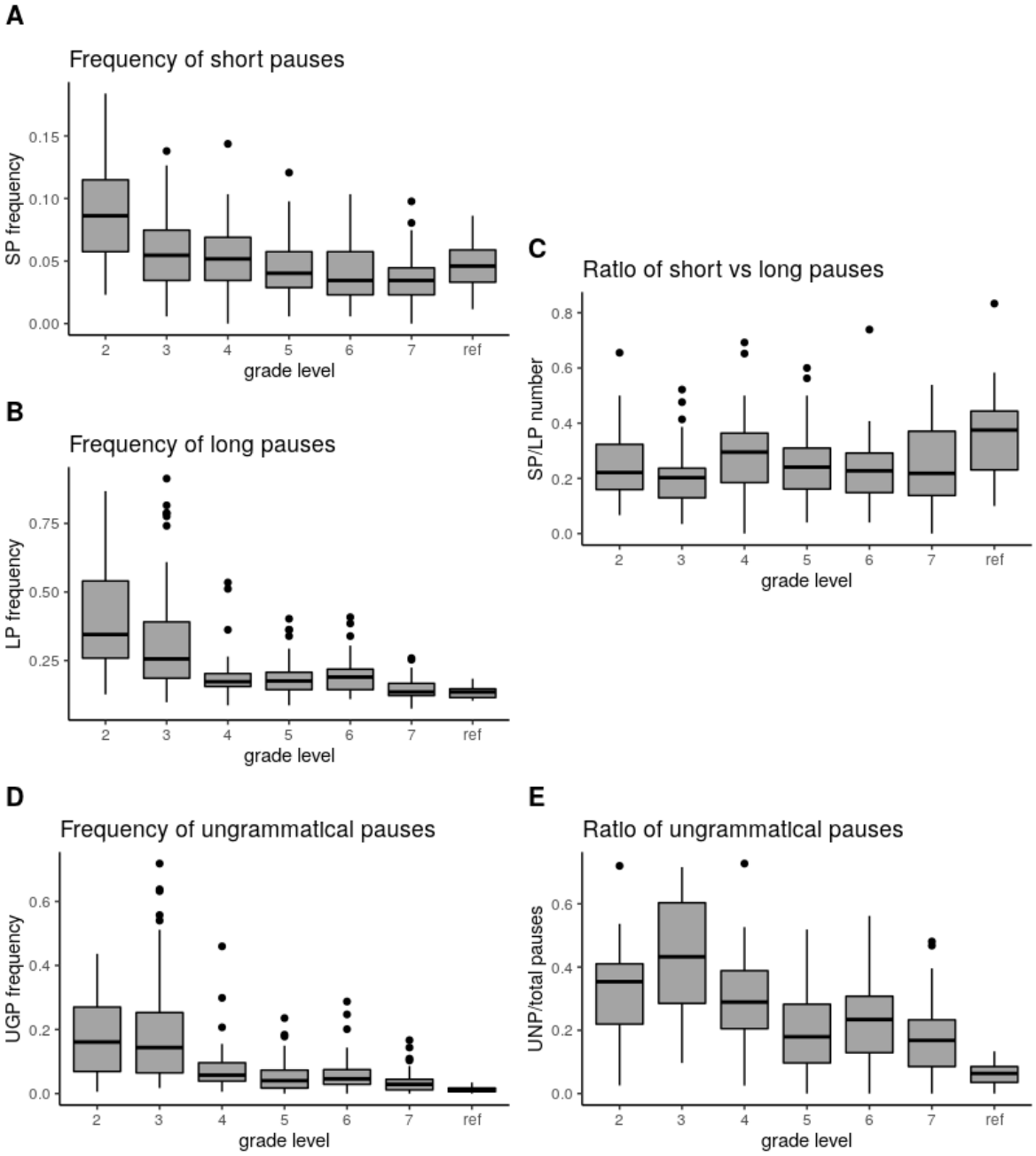

Figure 4: Boxplots of pauses frequency according to grade level: frequency of short pauses (A), long pauses (B) and ungrammatical pauses (D) according to grade level, ratio of short and long pauses (C), ratio of ungrammatical pauses (E) according to grade level.

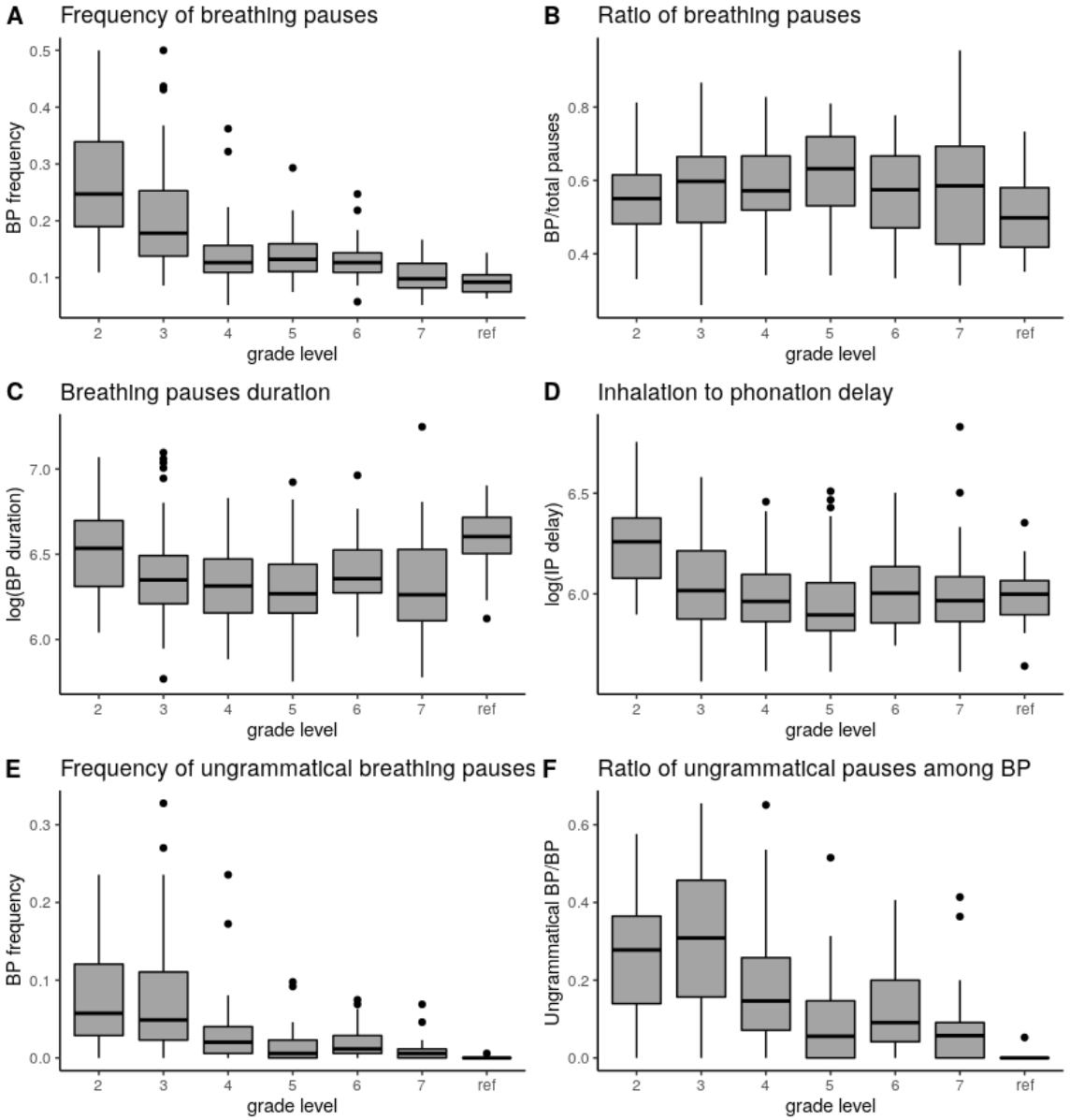

Figure 5: Boxplots of breathing pauses from grades 2 to grade 7 and adults : frequency of breathing pauses (BP) (A), percentage of BP among the total pauses (B), BP duration with log transformation (C), inhalation to phonation delay (IP) after log transformation (D), frequency of ungrammatical BP (E) and ratio of ungrammatical pauses among BP (F)

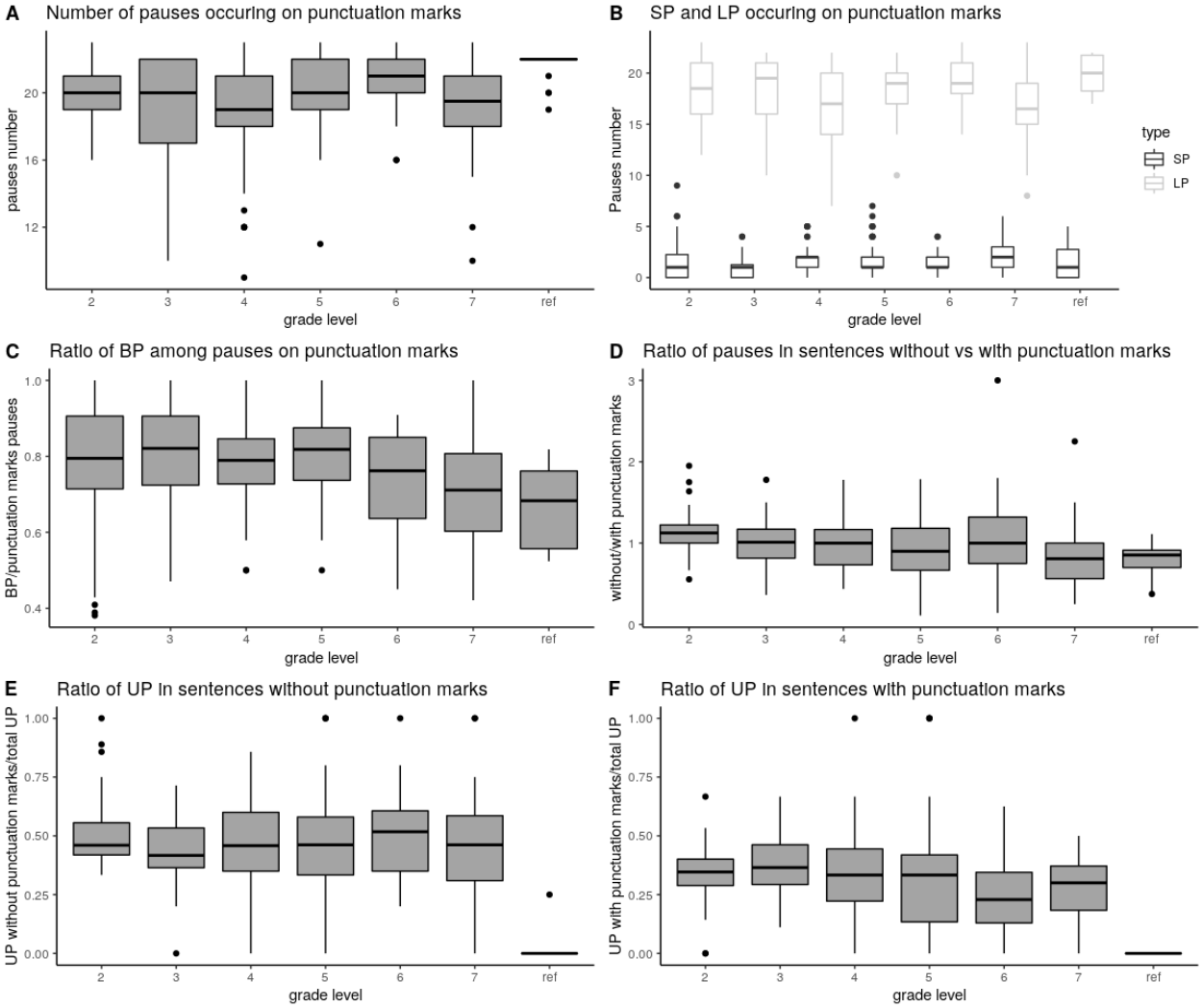

Figure 6: Boxplots of pauses occurring at punctuation marks for readers in grades 2 to 7 and adults : number of pauses occurring at punctuation marks (A), number of short and long pauses occurring at punctuation marks (B), ratio of punctuation marks used to breathe (C), ratio of pauses in long sentences 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).

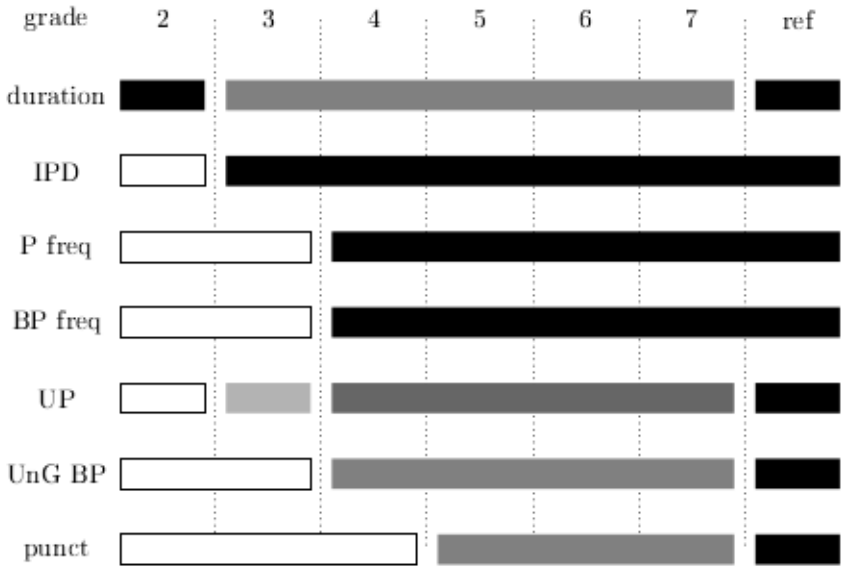

Figure 7: Summary of the results on pausing acquisition in reading development. Black corresponds to adult-like values. Level of grey for children darkens for values closest to adults values. The parameters presented in this scheme are long pause duration, inhalation to phonation delay (IPD), frequency of pauses (P nb), frequency of breathing pauses (BP freq), ungrammatical pauseing(UP), ungrammatical breathing pauseing(UnG BP), and number of ungrammatical pauses occurring in long sentences with punctuation (punct).