

Length effect in reading and lexical decision: Evidence from skilled readers and a developmental dyslexic participant

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Accepted 12 February 2004
Available online 17 April 2004

Abstract

A number of experimental data have shown that naming latency increases with length for pseudo-words but not for frequent real words. Different interpretations have been proposed by current models of reading to account for such a length effect. The aim of the present study was to assess the impact of lexicality on length effect in both the reading and lexical decision tasks. For this purpose, skilled readers were asked to either name or make a lexical decision on words and pseudo-words differing in length from one to three syllables. Skilled readers' results show that length effect is modulated by lexicality in the reading task but no length effect was found in the lexical decision task. The tasks were further proposed to a well-compensated dyslexic participant who exhibited a visual attentional disorder in the absence of any associated phonological problems. A length effect on RTs was found for both words and pseudo-words in lexical decision but naming latencies were affected by length for the pseudo-words only. The present results largely conform to the predictions of the ACV98 model of reading. They are not compatible with the PDP models of reading and can only be partially accounted for by dual route models.

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1. Introduction

Many studies have reported that naming latency increases with pseudo-word length, however, no length effect was found for frequent real words (Ans, Carbonnel, & Valdois, 1998; Baciú et al., 2001; Ferrand, 2000; Weekes, 1997). The explanation of such findings remains a challenge for current reading models.

Classical dual route models (Coltheart, 1978; Coltheart, Curtis, Atkins, & Haller, 1993; Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001) postulate the existence of two parallel routes, a lexical and phonological one, to convert print to sound. The lexical route is dedicated to real word reading; it allows access to word knowledge stored in a mental lexicon elaborated during reading acquisition. Word access is not sensitive to length so that naming latency is not affected by word length as far as words are frequent enough to be lexically processed. Within this framework, novel words and pseudo-words

are processed sequentially by the phonological route of reading. So, the longer the items, the longer phonological processing is to generate their pronunciation. Dual route models therefore predict differential length effects for words and pseudo-words in reading. No length effect is expected for either words or pseudo-words in lexical decision. Indeed, accurate lexical decision can be made on the basis of the orthographic lexicon overall level of activation (Coltheart et al., 2001) and lexical activation is not sensitive to input length.

At the opposite, PDP models (Harm & Seidenberg, 1999; Plaut, McClelland, Seidenberg, & Patterson, 1996; Seidenberg & McClelland, 1989) postulate that words and pseudo-words are all read aloud by a single uniform procedure based on the activation of lexical knowledge. Such models do not predict any length effect in either reading or lexical decision whatever the nature of the item to be read since all types of items are processed globally without involving any serial procedure.

As PDP models, the multi-trace memory model of polysyllabic word reading (Ans et al., 1998; ACV 98 hereafter) hypothesises a single mechanism to read

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words and pseudo-words although assuming the existence of two reading procedures (global and analytic) as in dual route models. However, the two reading procedures do not work in parallel; the global procedure always proceeds first, the analytic procedure only applying secondarily when global processing has failed. Known words are globally processed by activation of word traces in episodic memory. An orthographic echo is generated on the basis of word traces activation together with a phonological echo. If the orthographic echo is identical to the orthographic input, then the phonological output is validated as the network response to the input. If the orthographic echo differs from the orthographic input, the phonological echo is inhibited and the system shifts in the analytic mode. The visual attentional window through which information is extracted from the input orthographic sequence is then restricted to the first part of the orthographic sequence (typically the first syllable) which has been accurately recreated during global processing. A corresponding phonological echo is generated over the phonological layer that constitutes the pronunciation of this first part of the input. The analytic procedure is then reiterated serially from left to right until the input is totally processed. Most novel words and pseudo-words are processed analytically, typically syllable by syllable. The model therefore predicts a length effect on naming latencies for pseudo-words only. No such effect is expected in lexical decision which follows from global processing. Indeed, this latter task relies on a comparison between the activation patterns of the two input and output orthographic layers before any shifting in analytic mode. If these two patterns are strictly identical, the decision will be positive. If they differ, then the decision will be negative and processing will stop at this point. This study first aims at assessing the impact of lexicality on length effect in skilled readers engaged in a reading and lexical decision task.

The performance of a well-compensated young adult dyslexic participant was further analysed to assess the ACV98 model's predictions. Within this theoretical framework, developmental dyslexia is viewed as following from either a phonological disorder preventing the establishment of the analytic procedure of reading or from a visual attentional disorder preventing the establishment of word specific knowledge required for global processing (Valdois et al., 2003). When the size of the processing attentional window is reduced, then reading and lexical decision are based on analytic processing whatever the lexicality of the item to be read. It was therefore expected that a strong length effect would characterise the performance of our dyslexic participant in both reading and lexical decision since his developmental dyslexia was associated with a visual attentional disorder in the absence of phonological problems.

2. Analysis of skilled readers performance

2.1. Method

2.1.1. Participants

Twenty-eight undergraduate psychology students from the University of Chambéry participated in the experiment. They were given course credit for their participation and were randomly selected for doing either the reading task (for half of them) or the lexical decision task (for the other half). All the participants were native speakers of French and reported normal or corrected-to-normal vision. Participants were tested individually during a 20-min session. They were not aware of the purpose of the experiment.

2.1.2. Material

The complete set of items consisted of 174 French words and 174 pronounceable pseudo-words. One hundred and twenty words and 120 pseudo-words were selected as experimental stimuli. One-third of the target words and pseudo-words were one-syllable long, one-third had two syllables, and the remaining third had three syllables. The words were selected on the basis of the BRULEX lexical database for French (Content, Mousty, & Radeau, 1990). They were words from low to medium frequency (mean log frequency = 277.2; standard deviation = 50; range = from 134 to 390). The experimental pseudo-words were created from the word stimuli. The bi- and three-syllable pseudo-words were build-up by recombining the syllables of the target words with the constraint that the syllable position remained unchanged (e.g., the pseudo-word "crovier" was generated using the first syllable of the word "crochet" and the second syllable of the word "gravier." Mono-syllable pseudo-words were generated by recombining the syllabic components (corresponding to the onset, nucleus, and coda) from mono-syllable words. All experimental items began with a stop consonant in order to trigger the voice key as soon as the participants started pronouncing the input item in the reading task. Half experimental items of each syllable length ended with a mute "e" since such words are very frequent in French and could not be discarded although being ambiguous as to their number of syllables. Two sets of 36 filler words and pseudo-words, half ending with a mute "e," were mixed with the experimental items. The filler words had a mean log frequency of 342.5 and began by either a vowel or a non-stop consonant. The 36 filler pseudo-words were build-up from the filler word syllables. The complete list of stimuli is given in Appendix A. It further included 36 practice items, 18 words, and 18 pseudo-words.

2.1.3. Procedure

The stimuli were displayed in lowercase letters (bold Courier New 22) in the centre of a 17 in. DELL PC

colour monitor. They were presented in black on a white screen and time presentation was controlled by E-prime software. The participants were seated 50 cm from the computer monitor. The items angular size varied from 2.4° to 6° for mono-syllabic items, from 4.1° to 7.9° for the bi-syllabic items, and from 6.8° to 10.1° for the three-syllabic items.

2.1.3.1. Aloud reading. Each trial began with a fixation point displayed at the centre of the computer screen for 500 ms followed by a white screen for 150 ms. The stimuli (word or pseudo-word) were presented one at a time and remained on the screen until the participant's response. A new white screen was then displayed for 1000 ms during which the experimenter recorded naming accuracy via keyboard. The participants were instructed to read each item aloud as accurately and as quickly as possible. The real-time clock in the computer timed response latencies in milliseconds from the appearance of the stimulus to the onset of the subject's response. Two successive blocks of 87 words of all syllable length (9 practice words and 60 experimental words mixed with 18 fillers) and two successive blocks of 87 pseudo-words were presented. Presentation order of the two word and pseudo-word lists was counterbalanced in a randomised way along the participants.

2.1.3.2. Lexical decision. The experimental procedure was the same as in reading but the participants were instructed to indicate as accurately and as quickly as possible whether the printed item was a real word or a pseudo-word by pressing keyboard buttons (response YES, right hand, key “,”; response NO, left hand, key “w”). The 348 items were presented in two blocks. The first block began with the 36 practice items (18 words and 18 pseudo-words) followed by the 120 target items mixed with the 36 fillers. The second block was composed of the remaining 120 target items mixed with the remaining 36 fillers. The presentation order of the two blocks was counterbalanced along participants.

For both tasks, two randomised orders of trial presentation were further designed from Excell 97 software.

Half participants were submitted to one trial order, the other half to the other order.

2.2. Results

The RTs longer than 1500 ms or shorter than 300 ms in either naming or lexical decision and the items yielding less than 75% accurate responses were discarded from the analyses. Sixty-one items (12 words of one syllable and 8 words of two and three syllables; 12, 8, and 13 pseudo-words of one, two, and three syllables, respectively) were discarded from the analysis because of having a correct response mean rate inferior to 75%. Each participant produced on average 6.83% ($SD = 2.81$, range = from 1.25 to 13) erroneous responses all tasks mixed.

2.2.1. Reaction time analysis

Mean reaction times (RTs) were analysed by participants ($F1$) and by items ($F2$) using an ANOVA including Task (reading or lexical decision) as a between-subject factor, Lexicality (word or pseudo-word), and Length (one, two or three syllables) as within-subject factors. The mean RTs recorded in reading and lexical decision for words and pseudo-words of one, two, and three syllables are presented in Fig. 1.

The lexicality effect was significant in reading [$F1(1, 26) = 123.91, p < .0001; F2(1, 173) = 754.28, p < .0001$]. Mean RTs were 158.6 ms slower for words (537.6 ms) than pseudo-words (696.2 ms). There was no significant length effect for words [$F1(2, 52) < 1, ns; F2(2, 173) < 1, ns$] but a strong length effect for pseudo-words [$F1(2, 52) = 47.41, p < .0001; F2(2, 173) = 70.03, p < .0001$]. The Lexicality \times Length interaction was highly significant [$F1(2.52) = 42.11, p < .0001; F2(2, 173) = 36.52, p < .0001$].

In the lexical decision task, the lexicality effect was also significant [$F1(1, 26) = 23.07, p < .0001; F2(1, 173) = 187.82, p < .0001$]. The mean RTs were 68.9 ms slower for words (561.2 ms) than pseudo-words (630.1 ms). Contrary to the reading task, there was no significant length effect either for words [$F1(2, 52) = 2.74, ns; F2(2, 173) = 1.22, ns$] or pseudo-words in the

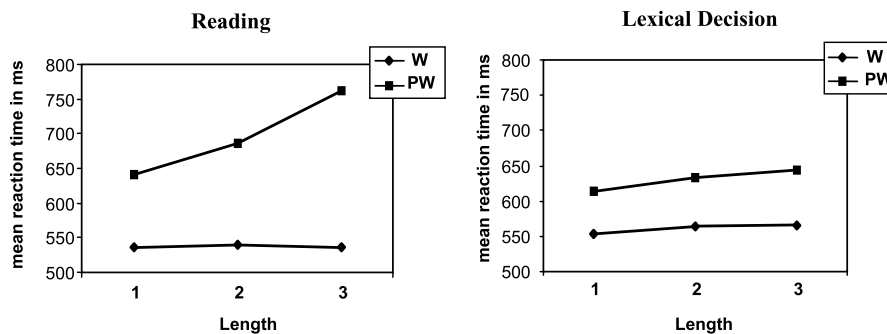


Fig. 1. Effect of interaction between length (one, two, or three syllables) and lexicality (W: word, PW: pseudo-word) according to the task, in skilled readers.

by-subjects analysis [$F1(2, 52) = 2.77$, ns]. A slight length effect was obtained for the pseudo-words in the by-item analysis [$F2(2, 173) = 5.11$, $p < .007$] but the Lexicality \times Length interaction was not significant [$F1(2, 52) < 1$, ns; $F2(2, 173) < 1$, ns].

The Length \times Task interaction was not significant for words [$F1(2, 52) = 1.19$, ns; $F2(2, 173) < 1$, ns], whereas it was very significant for pseudo-words [$F1(2, 52) = 14.2$, $p < .0001$; $F2(2, 173) = 23.58$, $p < .0001$].

Furthermore, the Lexicality \times Length \times Task second-order interaction was highly significant [$F1(2, 52) = 16.08$, $p < .0001$; $F2(2, 173) = 15.43$, $p < .0001$].

2.2.2. Error analysis

The raw error scores were analysed by participants ($F1$) and by items ($F2$) with an ANOVA using the same factors as in the previous analysis.

In the reading task, a lexicality effect was found by participants only [$F1(1, 26) = 5.23$, $p < .03$; $F2(1, 234) = 2.37$, ns] showing that error rate was higher for pseudo-words (9.2%) than for words (6.7%) (see Table 1). Length effect was significant for words and pseudo-words in the by participants analysis only [$F1(2, 52) = 7.04$, $p < .002$ and $F1(2, 52) = 6$, $p < .005$; $F2(2, 234) = 2.79$, ns and $F2(2, 234) = 1.58$, ns for words and pseudo-words, respectively]. Error rate decreased with word length but increased with pseudo-word length. The Lexicality \times Length interaction was significant [$F1(2, 52) = 9.8$, $p < .0003$; $F2(2, 234) = 3.70$, $p < .03$].

None of the effects or interactions taken into account in the RTs analysis reached significance in the error analysis with respect to the lexical decision task (all F s less than or close to 1). The Lexicality \times Length \times Task second-order interaction was significant [$F1(2, 52) = 8.73$, $p < .0006$; $F2(2, 234) = 4.36$, $p < .02$]. In sum, the error rate pattern is in no way the reverse of the RTs pattern in either task, thus showing the absence of trade-off between RTs and error rates.

2.3. Discussion

The analysis of the performance of skilled readers reveals that length effect on naming latency is modulated by lexicality. A strong length effect characterises pseudo-

word reading, whereas three-syllable words are named as quickly as one-syllable words. In contrast, no length effect is found in lexical decision whatever the nature of the items. The absence of length \times task interaction on words supports the hypothesis that words are processed globally in the two tasks. In contrast, this interaction is very significant for the pseudo-words as expected if pseudo-word naming relied on analytic processing, whereas lexical decision was based on global processing. This is supported by a very significant Length \times Lexicality \times Task second-order interaction. These overall findings conform to the ACV model's predictions but they are also compatible with the dual route theoretical framework. However, such findings do not support PDP models of reading which predict that length should not affect reaction time in either reading or lexical decision. It is further noteworthy that naming RTs for three-syllable words are lower than naming RTs for one-syllable pseudo-words. Such a result seems more compatible with the ACV98 model which assumes that global processing always precedes analytic processing. The fact that all words are named more quickly than all pseudo-words whatever their length is not a straightforward prediction of dual route models which postulate two reading procedures working in parallel.

3. Analysis of the performance of a developmental dyslexic participant

3.1. Case report

JPF is a graduate student in computer engineering who was 23 years 7 months old at the time of testing. He is a right-handed male native French speaker of good average intelligence (IQ = 115 as estimated from the Binois–Pichot vocabulary test). Hearing was found to be normal as well as visual acuity. JPF reports difficulties in reading and spelling acquisition from the second grade but he was never diagnosed as dyslexic and received no special help for his learning problems. He acknowledged he did not like to read and avoided reading as often as possible. On the “Alouette Reading Test” (Lefavrais, 1965), JPF achieved a reading age of 10 years 5 months

Table 1
Mean error rates (mER) and standard deviations (SD) according to lexicality (word and pseudo-word), syllable length (one, two, and three syllables), and nature of the task (reading and lexical decision) in skilled readers

Task		Word			Pseudo-word		
		One syllable	Two syllables	Three syllables	One syllable	Two syllables	Three syllables
Reading	mER	10.2	6.38	3.8	8	7.5	12
	SD	6.4	4.9	3.6	3.6	3.5	5.3
Lexical decision	mER	7.9	4.8	7.1	6.3	5.2	3
	SD	6	3.8	4.8	5.6	3.5	2.3

demonstrating the persistence of severe reading difficulties. His poor reading level was due to a very slow reading speed despite good accuracy of performance. JPF was submitted to a comprehensive battery of neuropsychological tests comprising oral language tasks, reading and spelling tasks, as well as tasks estimating verbal short term memory abilities. His results on these different tasks are summarised in Appendix B. They are compared to the performance of 25 normal readers matched for reading age and to the performance of one non-dyslexic reader of the same chronological age.

Overall, JPF performance was excellent on all tasks of oral language. He also demonstrated very good verbal short term memory abilities. Although his reading performance was comparable in accuracy to that of the CA matched participant, JPF's reading speed was slow on all kind of items. Finally, his spelling score was perfect on pseudo-words but he demonstrated a lower than expected performance in both regular and irregular word spelling. All his spelling errors were phonologically plausible and errors on regular words were mostly due to the incorrect reduplication of some consonants (e.g., frite → fritte).

Further assessment was conducted in order to highlight the existence of some phonological or visual attentional disorder associated with JPF's dyslexia. He was submitted to four metaphonological tasks: (1) a task of phoneme deletion which required to delete the first sound of a word and produce the resulting pseudo-word (e.g., "outil" /uti/ → /ti/; "placard" /plakaR/ → /lakaR/); (2) a task of phoneme segmentation requiring to successively utter each constitutive phonemes of a word previously pronounced by the experimenter (e.g., "fontaine" → /f/-/ ô/-/t/-/ E/-/n/); (3) a spoonerising test that required exchanging the first phonemes from two heard words (e.g., banane ficelle → fanane bicelle); and (4) a syllable deletion task in which a four-syllable word was orally produced followed by a number (2 or 3) that indicated the syllable to delete (e.g., mathématiques /matematiK/, 3 → /matetiKs/). Two visual attentional tasks were further proposed: the *whole report task* consisted in the presentation of a five-letter string (e.g., R H S D M) at the centre of the display monitor for 200 ms. The participant's task was to report verbally all letters immediately after they disappeared. The *partial report task* was similar to the previous one but a vertical bar appeared under one letter of the string immediately at the offset of the stimulus array. JPF had to report only the letter indicated by the cue (see Valdois et al., 2003, for a complete description of these two tasks). JPF's performance was compared to that of non-dyslexic young adults on these different tasks.

He demonstrated very good metaphonological skills. His performance was similar to the best scores of skilled readers and all tasks were realised very quickly without any hesitation or difficulty. Evidence for good phoneme awareness, good performance in oral language tasks,

and good verbal short term memory abilities suggest the absence of any phonological deficit associated to JPF's developmental dyslexia.

JPF's score in the whole report task did not differ significantly from that of skilled readers ($Z = 0.94$; ns). However, his performance was significantly poorer than that of the non-dyslexic participants in the partial report task ($Z = -6$; $p < .0001$). His pattern of performance was very atypical on this latter task where JPF demonstrated very poor abilities to identify letters in the second position of the string. Such findings suggest that a visual attentional disorder might have been responsible for his difficulties in learning to read and spell although this disorder was largely overcome at the time of testing.

3.2. Investigation of reading and lexical decision performance

3.2.1. Method

JPF was submitted to the two reading and lexical decision tasks previously described. However, the design of the experiments was slightly modified given that JPF was submitted to these two tasks successively. To avoid learning effects, he was presented with different items in the two tasks so that each task comprised 174 items only. The lexical decision task was presented first; it included a first block of 18 practice items (9 words and 9 pseudo-words) followed by the 120 target items (60 words and 60 pseudo-words) mixed with the 36 fillers (18 words and 18 pseudo-words). The reading task was given second; JPF was presented with a first list of 87 words of all syllable length (9 practice items, then 60 target words mixed with 18 fillers) followed by a list of 87 pseudo-words having the same characteristics. The procedure was the same as previously described.

3.2.2. Results

Nineteen items (4 words of one and two syllables and 1 three-syllable word; 2, 5, and 3 pseudo-words of one, two, and three syllables, respectively) were discarded from the analysis because they yielded an incorrect response. The mean RTs of JPF recorded in each task for words and pseudo-words of each syllabic length (one, two and three) are presented in Fig. 2.

Reaction times (RTs) were analysed using a general ANOVA including Task (reading aloud vs. lexical decision), Lexicality (word vs. pseudo-word), and Length (one, two or three syllables) as between-item factors. In reading, results show a significant lexicality effect [$F(1, 209) = 44.74$, $p < .0001$]. Mean RTs were 236.4 ms slower for the words (861.8 ms) than for the pseudo-words (1098.2 ms). Length effect was not significant for words [$F(2, 209) = 1.03$, ns] but a strong and significant length effect characterised pseudo-word reading [$F(2, 209) = 12.8$, $p < .0001$]. The Lexicality \times Length interaction also was significant [$F(2, 209) = 3.22$, $p < .05$].

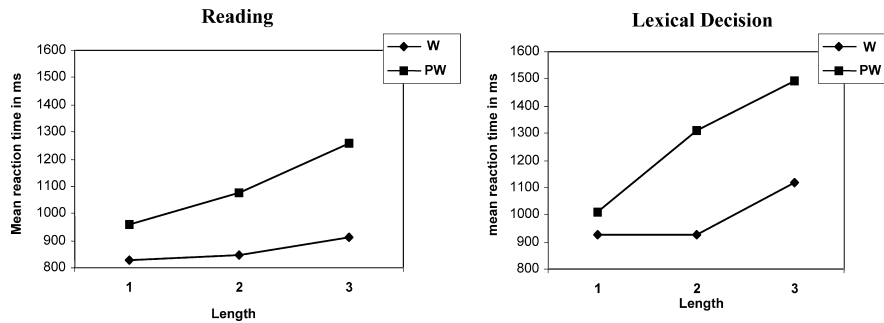


Fig. 2. Effect of interaction between length (one, two, or three syllables) and lexicality (W: word, PW: pseudo-word) according to the task, in JPF.

The lexicality effect was also significant in lexical decision [$F(1, 209) = 60.46, p < .0001$]. RTs were 280.7 ms slower on average in the word (990.5 ms) than in the pseudo-word condition (1271.2 ms). Contrary to the reading performance, length effect was found to be significant both for words [$F(2, 209) = 6.42, p < .002$] and pseudo-words [$F(2, 209) = 29.6, p < .0001$]. The Lexicality \times Length interaction also was significant [$F(2, 209) = 7.49, p < .0008$] showing that length effect was stronger for the pseudo-words than for the words.

The Length \times Task interaction was not significant for words [$F(2, 209) = 1.23, ns$] while it was significant for pseudo-words [$F(2, 209) = 3.06, p < .05$].

However, the Lexicality \times Length \times Task second-order interaction was not significant [$F(2, 209) = 1.36, ns$].

3.3. Discussion

The analysis of JPF's reading performance revealed that lexicality modulated length effect on naming latencies. Long pseudo-word naming took more time than short pseudo-word naming, whereas the naming latencies of words were not affected by length. Length effect also characterises RTs in lexical decision for both words and pseudo-words suggesting that the decision to accept or reject the input item as a real word or a pseudo-word was based on an analytic procedure rather than a global one. However, such an interpretation does not seem to be a priori compatible with the reading data since the existence of differential length effects on words and pseudo-words in reading rather suggests that these two kinds of items are processed differently. The absence of length effect on word naming latencies might reflect global processing, whereas the length effect observed on pseudo-words would result from analytic processing. However, the absence of significant Lexicality \times Length \times Task second-order interaction suggests that the two tasks are characterised by essentially similar patterns of performance and probably rely on analytic processing. The absence of length effect on words in reading might then be due to the fact that words and pseudo-words were presented by blocks in this task so that words could be guessed on the basis of just a partial

analysis of their constituent letters. A guessing strategy was particularly efficient in this task since words were selected to have no orthographic neighbours. It is also noteworthy that time needed to reject pseudo-words in the lexical decision task was 324 ms longer on average than time needed to name pseudo-words. This suggests that lexical decision was not based on a recognition procedure but rather follows from the generation of the item phonological form.

4. General discussion

The aim of this study was twofold. Our first purpose was to validate the predictions of the ACV98 model with respect to skilled reading. This model predicts that familiar words are processed globally whatever their length, whereas the analytic procedure of reading applies to unfamiliar words. In this latter case, the input letter string is typically processed syllable by syllable so that a length effect is expected to affect naming latency. A length effect on naming latency was therefore expected for pseudo-words only. According to this prediction, the analysis of the performance of skilled readers revealed that word naming latency was not affected by syllable length, whereas pseudo-words were named all the more slower that they increased in length. According to the ACV model, lexical decision is based on a recognition process which follows from global processing without any involvement of the analytic procedure. Accordingly, no length effect should affect lexical decision reaction times whatever the nature of the input item. As expected the analysis of skilled readers' performance in lexical decision showed that reaction times were not affected by syllable length whether the items were words or pseudo-words.

Overall, the present findings conform to the predictions of the ACV98 model. They are also compatible with the predictions of the dual route model but not with PDP models of reading which postulate that a single global procedure of reading applies to all kind of items, be they words and pseudo-words.

The ACV98's model further postulates that the global and analytic reading procedures apply successively rather

than in parallel, as hypothesised by dual route models. A straightforward consequence of this theoretical assumption is that all words whatever their length should be named more quickly than all pseudo-words. In support to this hypothesis, the present findings revealed that the longer words (i.e., three-syllable words) were named more quickly than even the shortest pseudo-words (i.e., one-syllable pseudo-words). This finding gives strong support to the ACV98 framework and seems not easy to reconcile with dual route models which assume that the global and analytic procedures run in parallel.

Our second aim was to validate the predictions of the ACV98 model with respect to dyslexia. This model postulates that two types of cognitive disorders can be responsible for developmental dyslexia. This reading acquisition disorder would first result from a phonological deficit which would disturb pseudo-word reading but have little effect in lexical decision. Accordingly, the absence of any length effect on reaction times should be expected in lexical decision tasks together with a normal length effect on pseudo-word naming latencies and the absence of such an effect in word naming. Length effect should therefore be very similar in skilled readers and in developmental dyslexics having a phonological problem, although more errors should be expected on pseudo-words due to the impairment of the analytic procedure. Such predictions were not assessed in the present study which focussed on the second account of developmental dyslexia.

Indeed, the ACV98 model further postulates that specific reading acquisition problems can also originate from a visual attentional disorder preventing the establishment of word traces in episodic memory. It then supposed that the visual attentional window through which orthographic information is extracted from the input cannot include the entire letter string so that the input items, words or pseudo-words, can only be processed analytically. It is therefore predicted that such a visual attentional disorder should result in a length effect in both reading and lexical decision for both words and pseudo-words. In the present study, the performance of a well-compensated young adult dyslexic was analysed in order to validate the ACV98 model. This dyslexic participant, JPF, still exhibited severe reading difficulties mostly due to a very slow reading speed. His very good metaphonological skills, his good performance in the oral language tasks, and his excellent verbal short term memory abilities suggested the absence of any associated phonological disorder. In contrast, he demonstrated some sequel of a visual attentional disorder although the disorder was largely overcome at the time of testing. As expected, JPF's performance in lexical decision was characterised by a strong length effect on reaction times for both words and pseudo-words, suggesting that lexical decision was based on analytic processing. A strong length

effect was also found on pseudo-word naming latencies but, contrary to our expectations, no such effect characterised word naming. Such a result suggests that words were not processed as pseudo-words in reading. However, naming latencies on words were not within the normal range since word naming latencies were on average 324 ms longer in JPF than in the non-dyslexic participants. It was hypothesised that a guessing strategy might have been used by JPF in word reading since words were presented by blocks and could easily be guessed on the basis of partial processing since they had no lexical neighbours. Such a guessing strategy is unlikely in the lexical decision task since real words are mixed with word-like items so that processing must be completed before the response is done. In support to this hypothesis, JPF's reaction times were 129 ms longer on average to accept words in lexical decision than to name them aloud, whereas RTs were slightly similar in both tasks for the non-dyslexic readers (non-significant difference of 23.6 ms, $F(1,26) = 1.1$, ns). The performance of the developmental dyslexic participant is therefore compatible with the predictions of the ACV98 model and suggests that a visual attentional disorder can affect both reading and lexical decision in preventing global processing. However, the dyslexic participant whose performance was analysed in this study had largely overcome his visual attentional deficit and further studies should be conducted in order to investigate the performance of dyslexic participants with more clear-cut visual attentional problems.

In conclusion, the present study reports data from both skilled readers and a developmental dyslexic participant which support the ACV98 model of reading. These data are not compatible with the PDP models of reading since they suggest the existence of two different procedures of reading. The existence of a length effect on naming latencies for pseudo-words only and the absence of such an effect in the lexical decision task whatever the nature of the item are also compatible with the dual route framework. However, this latter class of models does not predict that naming latency will always be lower for words than for pseudo-words whatever their length. Such a finding can easily be interpreted within the ACV98 framework since all words whatever their length are processed globally and global processing always proceeds first. Within this latter framework, pseudo-word naming latency reflects time needed for global processing to fail plus time needed for the analytic procedure to serially scan the whole letter sequence. Accordingly, naming latency for even very short pseudo-words should always exceed naming latency required to process even long words globally. Such a difference in word and pseudo-word naming latency is not straightforwardly predicted by dual route models

and does not support the hypothesis of two reading procedures working in parallel. Finally, the impact of a visual attentional deficit on reading and lexical decision is only compatible with the ACV98 framework since dual route models postulate that the same visual analysis procedure is involved whatever the reading procedure.

Appendix A

A.1. Practice words

flèche, choix, sac, quête, cure, œuf, abri, château, recette, schéma, impôt, justice, écurie, aliment, signature, symphonie, opéra, atmosphère.

A.2. Practice pseudo-words

cuf, flax, soic, oeute, clèche, quère, acufure, riteau, imma, juspôt, acetite, schetice, silirie, châbri, égnament, atphora, omosnie, sympéphère.

A.3. Target words

banc, biais, bloc, bourg brut, clerc, clos, crabe, craie, crêpe, croûte, drap, glas, golf, grade, grippe, gris, grue, guêpe, malt, mets, musc, niais, nœud, nord, pioche, pouls, prêt, quille, talc, tank, taupe, teint, test, thème, thon, thym, tresse, truie, tube, beignet, brasier, brigade, clameur, clôture, convoi, crapaud, cristal, critère, crochet, croquis, dauphin, dessert, diamant, discret, dossier, gradin, gravier, grillage, guépard, guirlande, guitare, manteau, mission, mistral, mosquée, mouflon, nombril, parade, pillage, pluriel, présage, tambour, tennis, thermos, toiture, torrent, transfert, trophée, tuyau, bâtiment, berlingot, bigorneau, brusquerie, carburant, complément, connexion, continent, cornichon, crocodile, dépendance, garantie, gratitude, guérison, manuscrit, marassin, ménestrel, monarchie, névralgie, nostalgie, parchemin, perpétuel, perroquet, porcelaine, précipice, préfecture, présidence, président, prévention, processus, projectile, propagande, protection, provision,

testament, tolérance, tourbillon, trajectoire, traversin, tribunal.

A.4. Target pseudo-words

bial, bioppe, bouis, brong, brost, clêt, clie, craupe, crite, crouche, crupe, dauc, diat, diur, douin, gat, grais, grède, grube, guerc, mand, meux, miau, nalf, neil, nioc, paud, pièppe, ploi, praie, psau, queint, quos, talf, teille, tesse, theu, thoue, tran, trope, bissier, bourtir, bravoï, bricard, carleux, chaillage, clagage, clonnis, consper, contare, corgnon, crécier, crituge, crovier, doutain, grafert, gralande, grisare, grosant, guirrade, guisier, martour, mautier, moucien, munnier, nécieux, nussant, pagon, pandeur, pitège, plasson, prédin, teillare, tocœur, toipaud, toureux, tournai, trachon, transture, tuchet, bârantion, belluquet, bétouillon, bragensif, brustidance, clafortin, comburance, croupession, cultaisie, déritude, gajecteur, goupliron, gracipile, grelanton, guéchiral, guésition, maidinier, mastainie, mengochet, mercoulot, mordageux, napprotal, palméteau, pendougie, poissulet, porquenal, poufequin, prébillon, préjectoire, prépament, prétilaine, procégance, prosacté, provendon, teccoudon, togrement, tourjectine, trapension, trichasson, trilédence.

A.5. Filler words

onde, vœu, fleuve, rein, arc, sphère, choc, âne, soin, os, chasse, rite, chemise, ardeur, organe, fauteuil, chausson, élève, section, légume, ivoire, ruban, outil, souplesse, adversaire, faculté, chocolat, entreprise, océan, vestibule, phénomène, restaurant, incendie, sentinelle, estomac, origine.

A.6. Filler pseudo-words

sphein, rère, arne, flasse, oute, onc, ade, chin, sove, rec, vios, cheu, orgat, fauteur, cheson, chanère, arban, égune, léteuil, souvoime, rution, iplesse, sectil, oumive, fataunelle, vescomac, ennodie, ocnprine, acégire, cho-verbu, intisaile, odrité, phétrerant, sentolat, esculanne, restimèse.

Appendix B

Performance of JPF on neuropsychological tests

	JPF	RA controls	CA control
Oral language tasks			
Verbal fluency			
Semantic criterion	57		34
Formal criterion	22		25
Vocabulary	28		27
Pseudo-word repetition	92/92		92/92

Appendix B (continued)

Reading tasks	Score	Time	Score	Time	Score	Time
Regular words	39/40	31 s	38.7 (1.2)	41 s	40/40	18 s
Irregular words	39/40	28 s	35.2 (2.6)	45 s	40/40	22 s
Pseudo-words	37/40	45 s	35.2 (2)	59 s	39/40	30 s
Spelling tasks						
Regular words	16/22		20.5 (1.6)		22/22	
Irregular words	18/22		16.3 (3.1)		20/22	
Pseudo-words	40/40		34/40 (3.3)		38/40	
Short term memory					Young adult norms	
Short word span	6/6				4.2 (0.9)	
Long word span	4/6				2.5 (0.8)	

Verbal fluency, number of words produced in 2 min; Vocabulary, score on the Binois–Pichot Test; Short and long word span, mean score in repetition of six lists of six short or long words (from the Côte-des-Neiges short term memory battery).

Performance of JPF on metaphonological and visual attentional tasks

	JPF		CA matched controls	
	Score	Time	Score	Mean time
Metaphonological tasks				
Phoneme deletion	20/20	43 s	18.7 (1.9)	51 s
Phoneme segmentation	20/20	63 s	16.4 (2.6)	70 s
Spoonerisms	10/12	62 s	10.3 (3.2)	104 s
Syllable deletion	19/20	88 s	18.7 (1.2)	98 s
Visual attentional tasks				
Whole report	96/100		97.5 (1.6)	
Partial report	45/50		49.2 (0.7)	

Whole report and partial report scores = number of letters accurately reported.

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