available at www.sciencedirect.com

SCIENCE DIRECT®

www.elsevier.com/locate/brainres

BRAIN RESEARCH

Research Report

Polysyllabic pseudo-word processing in reading and lexical decision: Converging evidence from behavioral data, connectionist simulations and functional MRI

S. Valdois[a,*], S. Carbonnel[a,b], A. Juphard[a,b], M. Baciu[a], B. Ans[a], C. Peyrin[a], C. Segebarth[c]

[a]Laboratoire de Psychologie et Neurocognition, UMR 5105 CNRS, Université Pierre Mendès France, BP 47, 38040 Grenoble cedex, France
[b]Université de Savoie, BP 1104, 73011 Chambéry cedex, France
[c]INSERM U594, Grenoble, F-38043 France, Université Joseph Fourier, Grenoble, F-38043 France

ARTICLE INFO

Article history:
Accepted 7 February 2006
Available online 30 March 2006

Keywords:
Reading
Lexical decision
Pseudo-word
Length effect
fMRI
Connectionist modelling

ABSTRACT

The cognitive mechanisms involved in polysyllabic pseudo-word processing—and their neurobiological correlates—were studied through the analysis of length effects on French words and pseudo-words in reading and lexical decision. Connectionist simulations conducted on the ACV98 network (Ans, B., Carbonnel, S., Valdois, S., 1998. A connectionist multiple-trace memory model for polysyllabic word reading. Psychol. Rev. 105, 678–723) paralleled the behavioral data in showing a strong length effect on naming latencies for pseudo-words only and the absence of length effect for both words and pseudo-words in lexical decision. Length effects in reading were characterized at the neurobiological level by a significant and specific activity increase for pseudo-words as compared to words in the right lingual gyrus (BA 19), the left superior parietal lobule and precuneus (BA7), the left middle temporal gyrus (BA21) and the left cerebellum. The behavioral results suggest that polysyllabic pseudo-word reading mainly relies on an analytic procedure. At the biological level, additional activations in visual and visual attentional brain areas during long pseudo-word reading emphasize the role of visual and visual attentional processes in pseudo-word reading. The present findings place important constraints on theories of reading in suggesting the involvement of a serial mechanism based on visual attentional processing in pseudo-word reading.

1. Introduction

The cognitive mechanisms underlying word recognition and reading have been intensively studied in recent years together with their cerebral correlates. A number of theoretical models—as the dual-route model (Coltheart et al., 1993, 2001), the PDP connectionist models (Harm and Seidenberg, 1999; Plaut et al., 1996; Seidenberg and McClelland, 1989) or the multitrace memory model (Ans et al., 1998)—based on distinct hypotheses about the structure of the cognitive reading system have been proposed to account for reading performance. However, most neuro-imaging data have been carried out within the dual-route framework (Jobard et al., 2003; Price et al., 2003). Through the analysis of length effects in reading

* *Corresponding author*. Laboratoire de Psychologie et Neurocognition, UMR 5105 CNRS, Université Pierre Mendès France, BP 47, 38040 Grenoble cedex, France. Fax: +33 4 76 82 78 34.
E-mail address: Sylviane.Valdois@upmf-grenoble.fr (S. Valdois).

0006-8993/$ – see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.brainres.2006.02.049

and lexical decision, the current paper shows evidence that, apart from dual-route models, connectionist models also provide a theoretical framework for the investigation of the neurological correlates of the reading system.

Our aim in the present paper was to study the cognitive mechanisms specifically involved in the processing of polysyllabic pseudo-words and to identify their neurobiological correlates. Length effects on words and pseudo-words in reading and lexical decision were studied for this purpose. Several experimental studies have investigated length effects in reading and/or lexical decision (Balota et al., 2004; Forster and Chambers, 1973; Hudson and Bergman, 1985; Klapp et al., 1973; Plaut, 1998; Spieler and Balota, 1997; Spoehr and Smith, 1973; Ziegler et al., 2001). In reading, length effect seems to be modulated by word frequency and varies according to the lexicality of the item to be read: an effect of number of syllables has been reported for low frequency words but not for high frequency words (Content and Peereman, 1993; Ferrand, 2000; Ferrand and New, 2003; Jared and Seidenberg, 1990; Mason, 1978). Strong length effects on naming latencies were consistently reported for pseudo-words (Ans et al., 1998; Mason, 1978; Ferrand, 2000; Ferrand and New, 2003; Weekes, 1997). A few data further suggest that length effects differentially affect brain activity during word and pseudo-word processing in reading (Baciu et al., 2001). With respect to lexical decision, no syllable length effect was reported for either words or pseudo-words (Ferrand and New, 2003; Frederiksen and Kroll, 1976; Richardson, 1976; see however New et al., submitted for publication).

The study was conducted within the framework of the connectionist multitrace memory model for polysyllabic word reading (Ans et al., 1998). The model postulates that two types of reading procedures, a global and an analytic procedure, are required for processing all kinds of letter strings. In contrast to the dual-route model, however, the two procedures operate according to a common set of computational principles and they do not work in parallel. Global processing always proceeds first, the analytic procedure applying only secondarily when global processing has failed. An orthographic and a phonological output are simultaneously generated following global processing. The phonological output is accepted as the global pronunciation of the input string if the orthographic output generated during processing is strictly identical to the orthographic input. When the two orthographic patterns differ, then the phonological output is inhibited and the system shifts in analytic mode. The system then processes the initial part of the input string which has been accurately recreated in output and processing is sequentially reiterated until the end of the sequence.

The two procedures mainly differ in the kind of visual attentional processing they involve. The whole orthographic object forms the focal window in global processing, whereas the visual attentional window is reduced to parts of the orthographic sequence, typically syllables, in analytic processing. Although the two procedures are not a priori dedicated to the processing of a particular type of letter string (real word or pseudo-word), it happens that most familiar words are processed as a whole, whereas global processing typically fails for pseudo-words. The system then shifts in the analytic mode and the pseudo-word is sequentially processed. The model thus does not predict any syllable length effect in familiar word naming, but a strong syllable length effect is expected in pseudo-word naming.

As all cognitive models, the ACV98 theoretical framework does not make clear-cut predictions at the neural level. However, one might expect that a similar network of cerebral regions should be activated during word naming whatever their length, if all familiar words were read globally. In contrast, cerebral activation should differ as a function of pseudo-word length. In the analytic processing of polysyllabic pseudo-words, each new syllable requires a new visual attentional capture for its pronunciation to be computed. Accordingly, the higher the number of syllables of a pseudo-word, the stronger should be the brain activation in the cerebral regions involved in visual and visual attentional processing.

The predictions are quite different with respect to lexical decision. Indeed, a decision about the familiarity of the input string is made on the basis of the orthographic output generated in global mode. If this orthographic output is strictly identical to the orthographic input, then a Yes response will follow. A No decision will be made when the orthographic output differs from the orthographic input. It follows that lexical decision only depends on processing in global mode, so that no syllable length effect should affect response latencies whatever the items' length or lexicality (words or pseudo-words). Thus, no additional brain regions should be activated when processing longer items as compared to shorter ones in lexical decision.

In the present study, the ACV98's predictions have been assessed using both behavioral and brain activation measures. Simulations were further conducted in order to check the theoretical predictions of the model. Experiment 1 used behavioral measures—reaction times (RTs) and error rates—to assess length effects in reading and lexical decision. The participants were presented with 72 words and 72 pseudo-words mixed with fillers. The experimental items varied in length from one to three syllables and from 4 to 11 letters. Two groups of young adults participated in the experiment: the first group was assessed in reading, the second in lexical decision. In reading, the participants were asked to read aloud the stimuli as quickly and as accurately as possible. In lexical decision, they had to judge whether or not each stimulus was a real French word. Reaction times and accuracy of response were recorded for each stimulus. Simulations of the reading and lexical decision performance were further conducted on the ACV98 network using the same set of items.

Experiment 2 assessed length effects using the event-related fMRI while participants performed the same reading and lexical decision tasks. Twenty healthy volunteers were examined: twelve during reading, eight during lexical decision. All were right-handed native French speakers with good reading level and normal or corrected to normal vision. The event-related fMRI paradigm (ER-fMRI) was used because this technique allows mixing several types of