SUBMITTED MANUSCRIPT

Phonology is Fundamental in Skilled Reading

Jane Ashby

Department of Psychology

University of Massachusetts, Amherst

(1,256 words)

Correspondence

Jane Ashby

Department of Psychology

661 Tobin Hall

University of Massachusetts, Amherst 01003

ashby@psych.umass.edu

There is controversy about the importance of phonology in skilled reading. Event-related potential (ERP) evidence from the initial moments of visual word recognition indicates that processing sub-lexical phonology is fundamental to skilled reading. The early timecourse of this phonological activation explains the predictive power of phonological awareness for early reading development, affirms the importance of phonological processing in learning to read, and illuminates the persistent challenges of dyslexia.

The cognitive representation of speech plays a central role in reading development. Phonological awareness, or the ability to segment and manipulate speech sounds, predicts first grade reading achievement, and phonological deficits are a primary factor in dyslexia[1, 2]. Whereas beginning readers rely on phonological decoding to identify the many unfamiliar words they encounter[3], children seem to recognize more words using direct access as they progress in reading[4]. Likewise, skilled adult readers often have the impression that they recognize printed words as wholes, using a direct visual route to lexical access. Phonological processes, then, are generally considered to be important for developing word reading skills, but their role in skilled reading is controversial. The present study reports neurophysiological evidence that skilled readers activate phonological representations within the first 100 ms of word recognition. This accounts for the central role of phonological processing in reading development.

Observing the time course of phonological processing in skilled visual word recognition is key to understanding phonology's role in reading. Previous neurobiological research has converged on the anatomy of neural activation during skilled word recognition[5], but fMRI lacks the temporal resolution to examine processes that operate within 0.25 seconds. Two masked-priming ERP experiments tested when skilled readers processed word-initial syllable information. Because syllables are not encoded explicitly in print, these experiments could manipulate sub-lexical phonology independent of visual form. They employed item pairs with different syllabification that were matched for initial trigram, such as SILENT and SILVER (available online in the Supplementary Methods). Target words were preceded by 44 ms masked primes that were congruent or incongruent with the initial syllable of the target (e.g., <u>si</u> or <u>sil</u>) as shown in Figure 1. Thus, congruency was independent of the visual characteristics of primes and targets in this design.

The predictions are straightforward. If skilled readers activate elaborated phonological representations, then syllable information should modulate ERPs as evidenced by a congruency effect. Early waveform modulation would indicate involvement in fundamental aspects of word recognition, whereas later modulation would complement existing evidence for phonology's role in sentence integration processes.

In both experiments, participants read single words silently while EEG was recorded. Semantic decisions (e.g., is it bigger than a shoebox?) were made via keypress on filler trials. The backward mask duration was manipulated between experiments.

Grand-average waveforms from 35 electrode sites were measured in 20 ms windows (60 – 700 ms). Potentials in each window were subject to repeated-measures ANOVAs (Greenhouse-Geisser corrected). Consecutive significant windows were combined to yield three main time windows: 100 -120 ms, 140 – 160 ms, and 340 – 380 ms. Signal processing details and other effects are reported in the online Supplementary Methods and Results.

Figure 2a shows the Experiment 1 data from 20 right-handed adults. Targets preceded by syllable-congruent primes elicited a smaller N1 (140 - 160 ms) than targets in the incongruent condition across 28 anterio-medial electrodes, $F(1,19)= 4.45$, $p=.048$.

Figure 2b shows the Experiment 2 data from 18 similar participants. Targets preceded by syllable-congruent primes elicited a smaller N1 (100 -120 ms) than targets in the incongruent condition across all electrodes, $F(1,17)= 6.37$, $p=.022$. Further, amplitudes over the left hemisphere, $F(1,17)= 9.01$, $p=.01$, were more negative in the syllable-congruent condition in the 340 - 380 ms window, $F(1,16)= 5.08$, $p=.04$.

ANOVAs conducted in 20 ms time windows tested interactions with Experiment. In the 340 – 380 ms window, there was an interaction of congruency, electrode, and experiment, F(6, 216)= 3.18, p=.034. This interaction confirms that the later congruency effect present in Experiment 2 over the left hemisphere is reliably different from the potentials in Experiment 1.

The most striking finding in these experiments was reduced N1 amplitudes to targets preceded by syllable congruent primes. The phonological congruency effect onset as early as 100 ms when reading words silently for meaning, indicating that fast phonological processing occurs during skilled word recognition. This study demonstrates the earliest neural mechanisms of automatic phonological activation yet observed at the suprasegmental level. The syllable congruency effect complements a recently reported sub-phonemic feature congruency effect that onset around 80 ms[6]. Combined, these studies indicate that phonological representations are detailed as well as quickly computed. These early phonological effects may be attributed to the use of identical primes and targets across conditions, which minimized physiological variance that may have masked early effects in previous studies[7].

The timing of the syllable congruency effect is earlier than would be expected if phonology functioned simply as a byproduct of lexical access that supported sentence integration processes[8,9,10,11]. Therefore, the present data suggest an additional role for phonology in skilled reading. If one accepts the emerging view that masked priming shares some properties with parafoveal processing[12], then it is possible that early phonological activation contributes to fluent (i.e., fast and accurate) reading by supporting initial compatibility-checks of parafoveally and foveally obtained word form information. This idea is consistent with previous findings of sub-lexical phonological congruency effects in the eye movement literature[13, 14].

The appearance of the syllable congruency effect on the N1 indicates that phonology is fundamental in skilled reading. This explains why phonological-processing deficits impair reading development and, conversely, why phonological awareness is a strong predictor of early reading achievement. Lastly, the fundamental role of sub-lexical phonology in skilled reading affirms the importance of phonics-based reading instruction to develop phonological coding skills for recognizing words in print.

References

1. Bradley, L., & Bryant, P.E. *Nature*, **301**, 419-421(1983).

2. Morris, R. D., et al. *J Educ Psychol*, **90**, 347–373 (1998).

3. Share, D. L. *Cognition*, **55**, 151-218 (1995).

4. Doctor, E. A., & Coltheart, M. *Mem Cognit*, **8**, 195-209 (1980).

5. Pugh, K.E., et al. *Learn Disabil Res Pract*, **16**, 240-249 (2001).

6. Ashby, J., Sanders, L.D., & Kingston, J. *Biol Psychol* (in press).

7. Penolazzi, B., Hauk, O., Pulvermuller, F. *Biol Psychol*, **74**, 374-388 (2007).

8. Hauk, O., et al. *J Cogn Neurosci*, **8**, 818-832 (2006).

9. Grainger, J., Kiyonaga, K., Holcomb, P.J. *Psychol Sci*, **17**, 1021-1026 (2006).

10. Friederici, A.D. *Trends Cogn Sci*, **6**, 78 -84 (2002).

11. Newman, R.L., Connolly, J.F. *Brain Res Cogn Brain Res*, **21**, 94-105 (2004).

12. Deutsch, A., Frost, R., Pollatsek, A., Rayner, K. *Lang Cogn Process*, **20**, 341-371 (2005).

13. Ashby, J., Rayner, K. *Lang Cogn Process*, **19**, 391-426 (2004).

14. Ashby, J., Martin, A.E. *J Exp Psychol Hum Percept Perform*, **34**, 224-236 (2008).

Acknowledgments

This research was supported by NIH grant HD051700. I thank Lisa D. Sanders, Chuck Clifton, and Keith Rayner for comments on previous versions of this paper, and Laura Giffin for her help collecting the data.

Figure Captions

Figure 1. The masked priming paradigm and the approximate location of the 35 scalp electrodes selected *a priori*. ANOVAs included four within participant factors: Prime-target Congruency, Target's Syllable Type, and Electrode Position (rows & columns) in a 2 x 2 x 5 x 7 design. As the target type was confounded with physical differences in the two sets of words, congruency effects that were evident across the full set of items are presented. Effects for each target type appear in the online Supplementary Results.

Figure 2. Syllable congruency effects in Experiments 1 and 2. The early, N1 effect is indicated by an arrow.

Figure – 1 Ashby

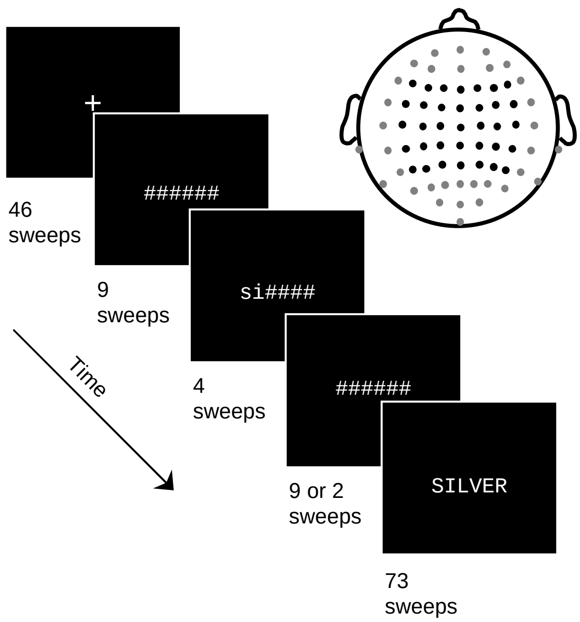

Figure 1

Figure - 2 A & B Ashby

Experiment 1

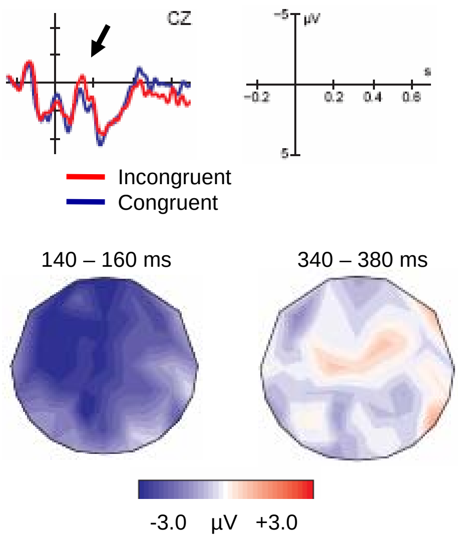

Figure 2A

Experiment 2

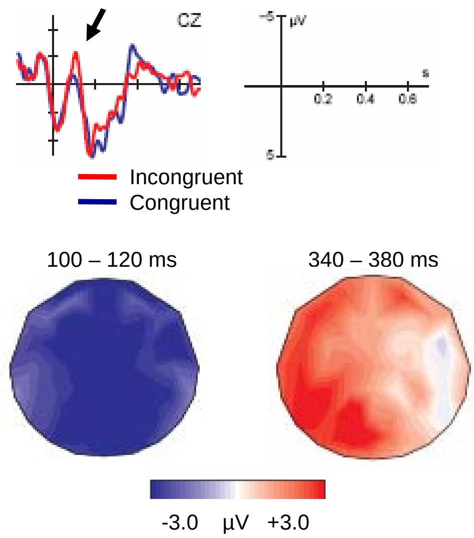

Figure 2B