Self-Paced Versus Fast-Paced Reading Rates and Their Effect on Comprehension and Event-Related Potentials

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ABSTRACT. Fifteen college-level readers (2 men and 13 women) were given 34 passages from the Test of English as a Foreign Language (TOEFL) for reading. During reading, event-related potentials (ERPs) were recorded from the midline sites (Fz, Cz, and Pz) of the participants’ scalps. The first 17 passages were read by the participants at their own natural rate (self-paced condition). The second 17 passages were read at a fast-paced rate determined by the fastest reading rate recorded on an adequately comprehended trial from the preceding passages. Results indicated that accelerating reading rate increased the readers’ comprehension. Additionally, the increase in reading rate and improvement in comprehension were reflected in the ERP measures. This finding confirms this study’s assumption that there is a disparity between reading ability and routine performance, and that this disparity is manifested in measures of neurocognitive functioning as reflected by the ERPs. Specifically, the ERP waveforms discriminated not only reading rate (specifically manifested by differences in speed of processing), but also the level of comprehension attained by the participants.

THE READING PROCESS can be described as involving three main factors: decoding, comprehension (Perfetti, 1985), and reading rate (Breznitz, 1987a). Researchers investigating these factors can use different means. Although behavioral measures have been traditionally used, such measures do not provide continuous information regarding the reading process itself (Bentin, 1989).
To access information about the cognitive processes involved in reading, we sought to augment behavioral measures of reading with the recording of the brain's electrical activity during reading performance, using the electroencephalogram (EEG). We measured the effects of increasing college students' reading rates on their comprehension of text and how this increase was reflected in the event-related potential (ERP). The ERP represents a time-locked response evoked in the EEG by an external stimulus. (Because the ERP itself is small in voltage compared with the background EEG, and as such is difficult to visualize in its raw form, we used an averaging technique to make the ERP stand out. Averaging is effective because the background EEG is assumed to be random, and therefore tends to average out, leaving only activity related to the stimulus in the recorded waveform.) The ERP is considered a neural correlate of information processing, and as such should provide information regarding the processing steps involved in reading (see Bentin, 1989; Kutas & Van Petten, 1986, for review).

In several studies, researchers have approached the interrelationships of reading rate, comprehension, and decoding in different ways. Many experimenters and theorists have suggested that reading rate is dependent on the effectiveness of decoding and level of comprehension of text (Carver, 1990; Gough & Tunmer, 1986). As a consequence, reading rate has become a diagnostic measure of reading ability (Perfetti, 1991; Stanovich, 1981).

Breznitz (1987a, 1987b, 1988, 1990) investigated the effect of reading rate on comprehension and decoding among elementary school readers in Grades 1 through 4. The results of these studies suggest that reading rate can be viewed as an independent variable that influences the quality of reading. Breznitz (1987a, 1987b) and Breznitz and Share (1992) manipulated reading rate in a series of experiments and predicted that gains in comprehension and decoding accuracy would be associated with accelerated reading rate. In these studies, reading rates were increased according to participant ability as determined by the participant's routine self-paced reading rate. This acceleration of rate (consistently about 20%, across several hundred subjects) was not set in an arbitrary manner, but was instead guided by the highest rate attained by the participant over a series of items read during the self-paced trials. Comprehension and accuracy were measured during slow-, self-, and fast-paced conditions. The results consistently indicated that increased reading rate led to better comprehension and reduced reading errors. Additionally, slowing the reading rate led to better decoding accuracy (i.e., the number of oral reading errors was reduced), but it also led to decreased comprehension (Breznitz, 1987a).

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Gains in accuracy and comprehension can be attributed to three factors. First, in theory, a faster reading rate increases the units available in working memory that can be allocated to reading and allows for a greater amount of contextual information to be used (Breznitz & Share, 1992). Second, the adoption of a faster reading rate lowers vulnerability to distraction (Breznitz, 1988). Finally, a faster reading rate may enhance the similarities between the vocal output of oral reading and familiar words in speech (Breznitz, 1990; see Breznitz, 1991, for a review).

In the aforementioned studies, all subjects were elementary school students from Grades 1 through 4. Early in the acquisition of reading skills there may be a discrepancy between reading ability and routine performance, a finding that is suggested by the differences between self- and fast-paced reading. Our purpose in the present study was to determine whether mature readers can also benefit from the acceleration of reading rate.

Psychophysiological studies of reading have been based primarily on the ERP techniques. Kutas and Donchin (1978), for example, examined the latency of the P300 component in a semantic discrimination task. The P300 is a positive polarity wave observed from 300 to 800 ms post-stimulus over central and parietal regions of the scalp, and researchers have theorized that it is related to context updating, that is, the revision of the schemata on the basis of newly acquired information in working memory (Donchin, 1981). Kutas and Donchin (1978) observed that P300 latency increased with the complexity of the semantic discrimination to be performed. Similar results were reported by Chabot and Waugh (1984).

A landmark in the psychophysiological study of reading was the discovery of the N400 component (for a review, see Kutas & Van Petten, 1986). The N400 is a negative-polarity wave, peaking at around 400 ms, recorded mainly over central and parietal regions of the scalp. The N400 is evoked by semantic incongruities or anomalies encountered during reading of text (Bentin, 1989; Kutas & Hillyard, 1980a, 1980b, 1980c; Kutas & Van Petten, 1986). In sentences without anomalies or incongruities, the amplitude of the N400 is markedly reduced or absent (Kutas & Hillyard, 1982).

In the present study we examined whether mature readers can derive the same benefit from the acceleration of reading rate that the elementary school children did. If so, we hypothesized that the increase in reading rate would be reflected by changes in the relevant ERP components—N1, P2, and N2—which relate to perception and attention. Additionally, we predicted that reading passages that were poorly comprehended would evoke an N400 response because of the subjectively experienced semantic ambiguity resulting from poor comprehension. Conversely, good comprehension would be reflected by an absent or smaller N400.
Method

Participants

The participants were 15 college students, 2 men and 13 women. Their ages ranged between 21 and 28 years, with a mean age of 24 years 4 months. All participants reported that they were right-handed and without history of neurological disorder. All participants were native English speakers.

Materials

Reading test. From preparatory workbook samples of the Test of English as a Foreign Language (TOEFL; Pyle, Munoz, & Bobrow, 1986), 34 short passages were used. Each passage contained a short declarative sentence, one line in length, followed by a multiple-choice question providing four alternative answers.

The 34 passages were divided into two sections with 17 pages in each. Each passage in each set was matched to an equivalent passage (in terms of reading time and level of comprehension) in the other set. To select and match the passages, we administered all 50 original passages to 60 university students. Reading time and level of comprehension were recorded for each passage and averaged across participants. A total of 17 pairs of passages were then matched.

Recording System

EEGs were recorded from tine electrodes sewed within a nylon elastic cap (Electro-cap international) with electrodes Fz, Cz, and Pz used and positioned according to the International 10–20 system. The Fpz lead of the cap served as a ground, and tin-plated ear electrodes linked together served as a reference. For artifact control, EOG was recorded from tin electrodes placed above and below the left eye.

EEGs were amplified by Grass Model 12 amplifiers, with the low frequency filter set at .1 Hz and the high frequency filter at 30 Hz. EEGs were sampled at a rate of 640 Hz over four channels for 1040 ms, triggered at stimulus onset.

Data collection was under the control of an IBM AT computer. Artifact rejection and averaging were done off-line. Data were stored on 1.2 MB floppy diskettes.

Procedure

The participants were tested in one session lasting approximately 40 min. They were seated in comfortable reclining chairs within a sound-proofed
chamber, and they faced an IBM computer screen. They were told that a series of English passages would be shown, each followed by two multiple-choice questions. The instructions were to read each sentence silently and then to select the correct answer. The study was done in two parts, a self- and a fast-paced reading session. Event-related potentials were recorded during the sessions, and the participants were instructed to refrain from blinking and to remain as still as possible.

**Part 1: Self-paced.** In this part, 17 passages were presented to the participants. Measures of reading time and comprehension were collected. The participants were instructed to immediately read each passage silently as it was presented on the screen. The participants controlled the appearance and disappearance of the passages by pressing a button with both thumbs as soon as they had completely read the passage. Immediately after the button was pressed the passage disappeared, and the multiple-choice question followed. An additional button press caused the question to disappear and be replaced by the next passage. The reading times for the passages and questions were tabulated by the computer.

**Part 2: Fast-paced.** An additional 17 passages were presented on the computer screen to the participants, this time requiring reading at a faster pace. To calculate the fast-paced reading rate we examined reading time for the self-paced passages on which comprehension questions were correctly answered. To control for the effects of passage length, we divided reading time by the number of letters in each passage. The fastest rate attained was used as the fast-paced reading rate. We used this procedure to ensure that the fast reading rate was within the demonstrated capacity of each individual.

Passages during the fast-paced condition were presented on the screen and then erased from the beginning, one word at a time, at the prescribed rate. After each passage was completely erased from the screen, a multiple-choice question was presented, as in the self-paced condition.

**Results**

Within-subject t tests were performed across conditions on the mean reading times and comprehension scores for each participant. The results revealed significant differences between the self- and fast-paced conditions in reading time, \( t(14) = 11.3, p < .02 \), and comprehension, \( t(14) = 3.6, p < .001 \). In the fast-paced condition the participants could read 12% faster than they normally could, and they increased comprehension scores on the fast-paced trials, \( M = 14.5 \, (SD = 3.1) \) versus slow-paced trials, \( M = 12.0 \, (SD = 4.3) \). This result amounted to an increase of 2.6 comprehension points on the passages for fast-paced trials.
The correlations between reading time and comprehension scores were $-0.56, p < .01$, for self-paced trials and $-0.64, p < .005$, for fast-paced trials. The correlation between fast- and slow-paced comprehension scores was $.83, p < .001$, and between fast- and slow-paced reading scores it was $.73, p < .001$.

The average waveforms in the self-paced condition revealed relatively high-amplitude N1 and P2 components in both comprehend and not-comprehend trials at 115 and 175 ms poststimulus (see Figures 1 and 2).

The P2 is followed by a slow, negative wave, peaking at about 350 ms, labeled N2. Later components show a difference between waveforms evoked on the comprehend and not-comprehend trials. When comprehension was poor (Figure 1), a prominent negative component was observed at 460 ms, followed by a positive component about 150 ms later (called N400 and P3, following Kutas & Hillyard, 1980a, 1980b, 1980c). On the comprehend trials (Figure 2), the N400 component was of longer duration and lower amplitude, delaying the onset of the P3.

Superimposed on the comprehend and not-comprehend trials is a slow, negative wave, with onset at the termination of the P2 component. On the comprehend trials, this wave showed a sharp return to baseline at about 850 ms poststimulus (Figure 2). On not-comprehend trials (Figure 1), return to baseline did not occur within the recording epoch.

The fast-paced condition was marked by low-amplitude N1 and P2 components of poor waveform morphology (see Figures 3 and 4). Again, a termi-

**FIGURE 1.** ERPs of poorly comprehended self-paced trials.
FIGURE 2. ERPs of adequately comprehended self-paced trials.

FIGURE 3. ERPs of poorly comprehended fast-paced trials.
nating slow, negative wave was observed on comprehend trials (Figure 4), and a nonterminating wave was seen on not-comprehend trials (Figure 3). The N400/P3 complex observed in the self-paced condition was not observed in the fast-paced trials, but a prominent complex of waveforms that occurred earlier and with somewhat different characteristics was noted. On the fast-paced poorly comprehended trials, P2 was followed by a sharp negative wave (referred to as N2) at about 230 ms. N2 was followed by a series of waves labeled P290, N350, and P450 (see Figure 3). On the comprehend trials we noted a similar series of waves of poor definition and lower amplitudes (Figure 4). Overall, the P450 seemed to distinguish between comprehend and not-comprehend trials in the fast-paced condition, with higher amplitudes and clearer waveform morphology noted on the not-comprehend trials for the component (Figures 3 and 4).

Discussion

The results of the present study indicate that normal readers at the college level can increase their reading rate by about 12% and comprehension scores by 21.8%. In our previous studies of elementary school readers we found that the children could be prompted to read at a rate that was about 20% faster than their routine reading rate, and additionally, they could increase comprehension and oral-reading accuracy (Breznitz, 1987b, 1990).
These results suggest that in disparate age groups there are marked discrepancies between reading ability and performance. Prompting a faster reading rate seems to allow the reader to actualize his or her potential reading proficiency. We propose that the increase in speed of processing prompted by our manipulation allows the individual reader to better allocate information-processing resources. Previous studies indicate that under the fast-paced condition, the units available to working memory increase (Breznitz & Share, 1992), and attention is maximized in reading because of a lowered susceptibility to distraction (Breznitz, 1987b). The high negative correlation between reading time and comprehension observed in the present study, as well as in our previous studies, indicates that the participants who read faster comprehend more. This finding has been demonstrated to be robust across age groups and abilities spanning from early elementary school to college-level readers.

In our model we assumed that information processing in the brain would reflect this speeded rate of processing manifested by the accelerated reading pace. Exactly how this is reflected in neural processing is shown in the electrophysiological data.

ERP waveforms revealed differences in evoked responses to slow- and fast-paced conditions and in comprehend and not-comprehend trials. Within the slow-paced trials (see Figures 1 and 2), prominent N1 and P2 components were noted. These were followed by a complex series of waves superimposed on a slow, negative wave with onset following P2 return to baseline. The negative component observed at about 460 ms was different, dependent on comprehension. The N460 evoked on the comprehend trials was a slow-going wave with a flat peak, whereas that evoked on not-comprehend trials was much sharper with an earlier return to baseline. Earlier researchers (Kutas & Hillyard, 1980a, 1980b, 1980c, 1982; Neville, Kutas, & Schmidt, 1982) determined that a negative component observed around 400 ms was evoked most strongly by semantic incongruities, anomalies, or ambiguities, whereas semantically congruous stimuli produced a reduced-amplitude or absent N400. In the present study, the N400 was more prominent when the participant had difficulty understanding what he or she was reading. This finding suggests that the participant experienced the meaning of some passages as semantically ambiguous, and consequently the participant showed a large N400 component. These results follow from the Kutas and Hillyard studies reviewed earlier; however, rather than ambiguity or incongruity following from an experimenter's manipulation, this study's semantic ambiguities were subjectively experienced.

The fast-paced trials were different from the slow-paced trials in that the observed components appeared much earlier in the recording epoch. The fast-condition waveforms (Figures 3 and 4) and the slow-condition waveforms (Figures 1 and 2) revealed that in the fast condition, a lower amplitude
N1-P2 complex was followed by a negative component at about 230 ms (N2). The slow-paced trials showed a large N1-P2 complex, followed by a slow, negative wave. We theorized that the N2 observed during reading (see Ku-tas & Van Petten, 1986, for review) is related to semantic selection; therefore in the present study, speeding in the reading process resulted in the acceleration of selection.

Immediately following N2 in the fast condition was a positive-negative-positive series of waves (labeled P290, N350, and P450). The P450 most clearly discriminates between comprehend and not-comprehend trials. When comprehension is poor, the P450 appears as a large-amplitude, sharp wave. In addition, although they were not as dramatic, the morphologies of the P290 and N350 were also clear during the not-comprehend trials; therefore, we concluded that this complex of components was also sensitive to semantic ambiguity.

We noted that the slow, negative wave, observed over all trials and conditions, was sensitive to comprehension. On the trials with good comprehension, the negative wave returned to baseline about 800 to 850 ms poststimulus. There was no return to baseline observed on the poorly comprehended trials. This processing negativity's morphology and duration suggest the involvement of a large group of neurons activated serially, possibly involved in the analysis of meaning, together in a common information-processing goal. Our conclusion is that this neuron activity represents a process ending in cognitive closure corresponding to the reduction of uncertainty that the process of comprehension entails.

In summary, the results indicate that increasing the reading rate increases reading comprehension of college-level readers. Additionally, these increases in comprehension and reading rates are reflected by changes in the ERP measures obtained. We theorize that ERPs will shed light on the component processes involved in reading. Because the recording sites (midline) were limited in this study, the direction of future work will focus on how these processes may be localized within the brain, as reflected by the component distribution across the scalp when a full array of electrodes is used.

REFERENCES


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