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Electrophysiological Correlates of Reading Processes in School Age Children

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Abstract

Orthographic and phonological decoding skills are known to be important for learning to read. In an attempt to develop physiologically based screening tools which may identify children at risk for developing these skills, Auditory Event Related Potentials (ERP) were recorded from 84 nine-year-olds to a series of Probe tones while they were engaged in a series of orthographic, phonological, and spelling tasks. Electrodes were applied over both hemispheres at the frontal, temporal, and parietal regions of the scalp. Analyses focus on the relationship between hemisphere differences and children's performance on each of these tasks.

Introduction

This study gathered normative data regarding orthographic and phonological decoding skills which are important to reading acquisition. In so doing, this study hoped to determine whether electrophysiological procedures, in the form of event related potentials (ERPs) can detect differences between orthographic and phonological processing. As a more objective measure of testing reading ability, ERPs could be a useful means to detect early reading problems. This study uses archival data which were collected as a part of a longitudinal study which employed electrophysiological measures to study language and cognitive development.

Literature Review

Humankind has been fascinated by the functions of the human brain for centuries. For example, in 3000 B.C. the ancient Egyptians examined and documented their study of the brain (Wagner, 1975). As early as 1861, the study of the brain became more specialized, as exemplified by Broca who found lesions at autopsy in the left hemispheres of individuals who had lost the ability to speak. This indicated a left hemisphere dominance in language (Broca, 1865). Shortly afterwards, Carl Wernicke (1848-1904) demonstrated that injury of a cortical area inside the Sylvian fissure lead to a type of aphasia characterized by comprehension deficits.

Since the time of Broca and Wernicke, both cerebral hemispheres have been studied intensively to determine the degree to which they are involved in language processing (Sarkari, 1994; Patterson & Besner, 1984; Zaidel, 1983).

While findings to date have indicated that damage to the left hemisphere results in a disruption of language that produces aphasias (LeCours, Lhermitte, & Bryans, 1983) and that the left hemisphere as well in average subjects, there is a growing body of literature which suggests that the brain's processing of language information is more dynamic and not restricted to traditional static views of laterality (Molfese, 1983).

The study of brain-language structures in the past relied heavily on lesion studies of the brain until 1924. In that year, the first scalp electrodes were used to measure the EEG patterns of human subjects (Wagner, 1975). Since then, other techniques, such as, dichotic listening, visual half field studies, PET, MRI, CT, and FMRI have proliferated. However, electrophysiological techniques involving evoked potentials remain the only technique to provide high temporal and processing information. More modern event related potential (ERP) techniques have been utilized to detect brain response patterns. ERPs are EEG patterns which are timelocked to a particular stimulus and its corresponding brain response (e.g., Molfese, Burger-Judisch, Gill, Golinkoff, & Hirsch-Pasek, 1996).

The present study investigates whether ERPs can discriminate between phonological (sound properties of words in a given language), orthographic (the rules each language uses to construct words from letters), and spelling skills in a group of nine-year-old children. This has important implications for the study of reading disabilities, since these behaviors have been found to be aberrant in this population. Reading has been extensively researched, due, in part to the fact that reading disabilities are a very common type of learning disability (Sarkari, 1994; Flowers, Wood, & Naylor, 1991; Hynd, Semrud-Clikeman, Lorys, Novey, & Eliopulos, 1990). A comparison of different methods of assessment such as the Woodcock Word Attack (Woodcock, 1973) and Wrat (Jastak & Wilkonson, 1984), in addition to neurophysiological measures, such as ERPs, could provide even more valuable insight into language difficulties. Moreover, if we can establish how reading related tasks involving phonological and orthographic judgements differ in average populations of children and apply some of these same procedures to reading disabled children, we may gain some insight into the bases for reading disabilities. As Sarkari (1994) and others have pointed out, undetected reading disabilities have a profound effect on the future academic success of a child, due, in part, to the great emphasis our society places on verbal skills.. Academic achievement is a factor in future achievement which impacts later occupation choice and socioeconomic status.

ERP procedures have already given some indication that insight in language difficulties is possible. For example, Callaway, Tueting, and Koslow (1978) and Molfese, Simos, & Sarkari (1995) reported that ERPs can discriminate differences in cognitive and linguistic performance (See also Rugg, 1984; Rugg & Barrett, 1987; Polich, McCarthy, Wang, & Donchin, 1987; and Molfese & Molfese, 1985). ERP data have been used extensively to study cognitive processes, especially word identification and other language-related processes in both adults and infants (Rugg & Barrett, 1987; Hillyard & Kutas, 1983; and Rugg, Kok, Barrett, & Fischler, 1986; Molfese, 1989; Molfese, 1990). Molfese (1983) found ERP techniques to be an especially useful method in the study of cerebral lateralization of language. ERPs have proven to be very helpful in the measurement of language difficulties, using a variety of behavioral testing techniques (i.e., orthographic and phonological measures). In addition to these, it is likely that neurophysiological measures can become effective screening tools.

The various factors just indicated reveal the different measures which have been utilized to study reading acquistion. However, reading disabilities can take a variety of forms and must be assessed using a variety of techniques. Stanovich, Cunningham, and Feeman (1994) point out that reading is made up of a vast constellation of skills, such as *phonological awareness, rapid decoding, verbal comprehension, and general intelligence.* These skills can be defined as, (1) phonological awareness or being cognizant of how a word should sound, based on its combination of letters, (2) rapid decoding or the ability to identify words quickly and without hesitation, (3) verbal comprehension, which is the ability to understand words alone and in a given context, and (4) general intelligence which underlies reading skills (Sattler, 1992). Sawyer (1992) states that proficiency in reading is dependent on language abilities, such as size of vocabulary, knowledge of syntax, auditory discrimination, and blending. Moreover, Sawyer found that in her four-year longitudinal study of 300 kindergartners, early language skills predicted later language ability. One aspect of language as noted by Molfese et al. (1995), the understanding of orthography, is an important aspect of reading ability. Moreover, increased knowledge of the rules of spelling may assist the child in learning to read unfamiliar words by phonological analogy (Glushko, 1979; Goswami, 1986; Manis, Custudio, & Szeszulski, 1993) or orthographic redundancy (Molfese et al., 1995). Spelling is yet another important component of reading (Manis, Custudio, & Szeszulski, 1993), as is comprehension. Olson, Forsberg, Wise, and Rack (1994) point out that comprehension is the most important aspect of reading in both below average and average readers. Thus, the study of individuals with reading disabilities, such as dyslexia, may shed light on the comprehension difficulties experienced by average readers (Smith, 1994). Given the many properties of reading acquisition, it is no wonder that many reading theories have emerged, such as dual process theory (Colheart, 1978; Van Orden, Pennington, & Stone, 1990), Analogy theory (Goshwami & Bryant, 1990), and Frith's model of reading acquisition (Sawyer, 1992). Each of these theories has contributed to our understanding of reading acquisition.

Theories of Reading Acquisition

One of the most favored theories of reading acquisition is the dual process theory (Smith, 1994). Crowder (1982) and Wagner and Torgenson (1982) point out that although writing represents language, the actual letters express something in between its sound and its meaning. Morton's (1969) dual process theory seems to follow what we recognize as the average pattern of reading acquisition. For example, dual process theory posits that a word's spelling is determined by its phonology according to an intricate relationship between letters (orthography) and sound structure (phonology) (Colheart, 1978; Van Orden et al., 1990). Molfese et al.

(1995) point out that this model makes the assumption that regular words indicate their pronunciation via a direct correspondence between their phonological and orthographic components (also known as assembled phonology). In contrast, irregular word pronunciation must be *phonology.* Barker, Torgenson, and Wagner (1992) investigated word identification utilizing non-word reading tasks with a group of 87 third-graders. They found that orthographic and phonological skills were factors in all tasks. However, although this appears to indicate that word recognition is a slow process, increased word familiarity makes the recognition appear nearly automatic (Olson et al., 1994). Nonetheless, there is some criticism of this approach; for example, Van Orden, Pennington, and Stone (1990) propose that dual process theory has misunderstood the connection between a word's spelling and its sound components (phonology). They believe that this theory fails to adequately account for the ability to pronounce words or even non-words (Van Orden et al., 1990). Nonetheless, this approach was shown to fit well with a hypothesis about why the left hemisphere is specialized for reading.

Another view, Marsh's Analogy Theory (1977), posits that children learn to read new words by making *analogies* to words which they already know and which have similar spellings to these known words (i.e., *play-stay*) (Goshwami & Bryant, 1990). In other words, this view suggests that words which appear similar to each other also tend to be pronounced in a similar fashion. This method appears to be a far easier method for learning to read than learning each word separately (Gough & Hilliger, 1980) or by utilizing phonological "sounding out strategies" (Goswami, 1980). However, this theory may be flawed for several reasons. For example, words that look alike do not always sound alike (e.g., *come & home*). In addition, Sarkari (1994) points out that many non-words are quite easy to pronounce, but have no models for their pronunciation (e.g., *vunhip*). Third, the use of analogies in spelling may be limited to older children and adults. This conclusion is based on a study of seven-year-olds, ten-year-olds, and college students which found that seven-year-olds did not use analogies at all, ten-year-olds used them only a third of the time, and college students used them only 50% of the time (Goswami & Bryant, 1990). These results weaken the "learning to read by analogy" hypothesis since these children and young adults failed to generalize spelling of non-words to real words.

The third theory is Frith's Model (1985), which proposes that certain cognitive processes are responsible for the successful acquisition of reading skills (Sawyer, 1992). Frith (1985) developed a stage theory of reading acquisition. These stages build on each other in order and include *logographic* (when a child learns that words are symbols for objects), *alphabetic* (when, in addition, the child learns to recognize letter-to-sound correspondences), and *orthographic* (recognition of letter patterns without the necessity of "sounding it out" strategies). If such skills fail to develop, the theory posits that this is due to a variety of personal and environmental factors (Sawyer, 1982). Support for this theory is offered by Read and Ruyter (1985; cited in Sawyer, 1992) who studied below average adult readers and found that they lacked certain language skills that had not been acquired through the maturation process.

The Present Study

In the present study, 84 nine-year-olds were tested to determine whether ERP techniques could discriminate between phonological, orthographic, and spelling skills. The ERPs, elicited by a 2000 hz tone probe stimuli, will be monitored as objective measures of reading ability. Since the probe is always the same, no differences should be seen in the exogeneous region of the ERP, while marked differences should be noted in the endogeneous region as a function of whether the child is processing this tone while engaging either orthographic or spelling skills.

Hypotheses

First, we expect to find that phonological measures will be discriminated more readily from visual or orthographic tasks. This hypothesis is given support by Vellutino, Scanlon, and Spearing (1995), who studied second and sixth graders and implicated phonological deficits as likely causes of reading problems. Moreover, Ehri (1989) proposes four explanations for how phonological factors affect reading ability. To elaborate, Ehri says that (1) phonological aptitude likely precedes reading, (2) phonological aptitude contributes to reading skill, (3) phonological ability may be a result of learning to read rather than providing assistance in reading, and phonological ability may be correlated to reading ability by some third variable. This emphasis on phonological processing is consistent with the dual process theory (Morton, 1969). Our second hypothesis is that since phonological processing is expected to occur primarily in the temporal lobe of the brain, we expect that ERPs recorded from over the temporal lobe will best discriminate phonological tasks from the other tasks.

Method

Subjects:

The 84 nine-year-olds (34 males and 50 females) in this study were part of a continuing longitudinal sample which involved recruiting these children and their parents shortly after the birth of the child and then testing the child at yearly intervals. All children were tested within one month of their ninth birthday.

Stimuli:

The probe stimulus is a computer generated tone of 2000 Hz that has a duration of 300 ms. The digitized tone was presented via a *stimulus presentation system* developed in the Molfese lab for a Macintosh computer (Molfese et al., 1995) at a loudness level of 75 db SPL(A).

Procedures:

The children were given the Siegel (1973) orthographic, phonological, and visual tests by behavior testers. Each test required the children to choose between two alternative words. The order of test presentation was varied across subjects using a Latin square design in an attempt to correct for order effects. During these tasks EEGs were recorded in response to presentations of the 2000 Hz tones from scalp electrodes placed at six scalp sites: left frontal (F3), right frontal (F4), left temporal (T3), right temporal (T4), left parietal (P3), and right parietal (P4). In addition, linked ear electrodes (A1, A2) were used as references. Electrode impedences were measured before and after testing and were all kept under 5kOhm and within 1kOhm of each other. Electrodes were placed at supra orbital and canthal positions relative to the right eye in order to detect eye artifacts which could contaminate the ERP.

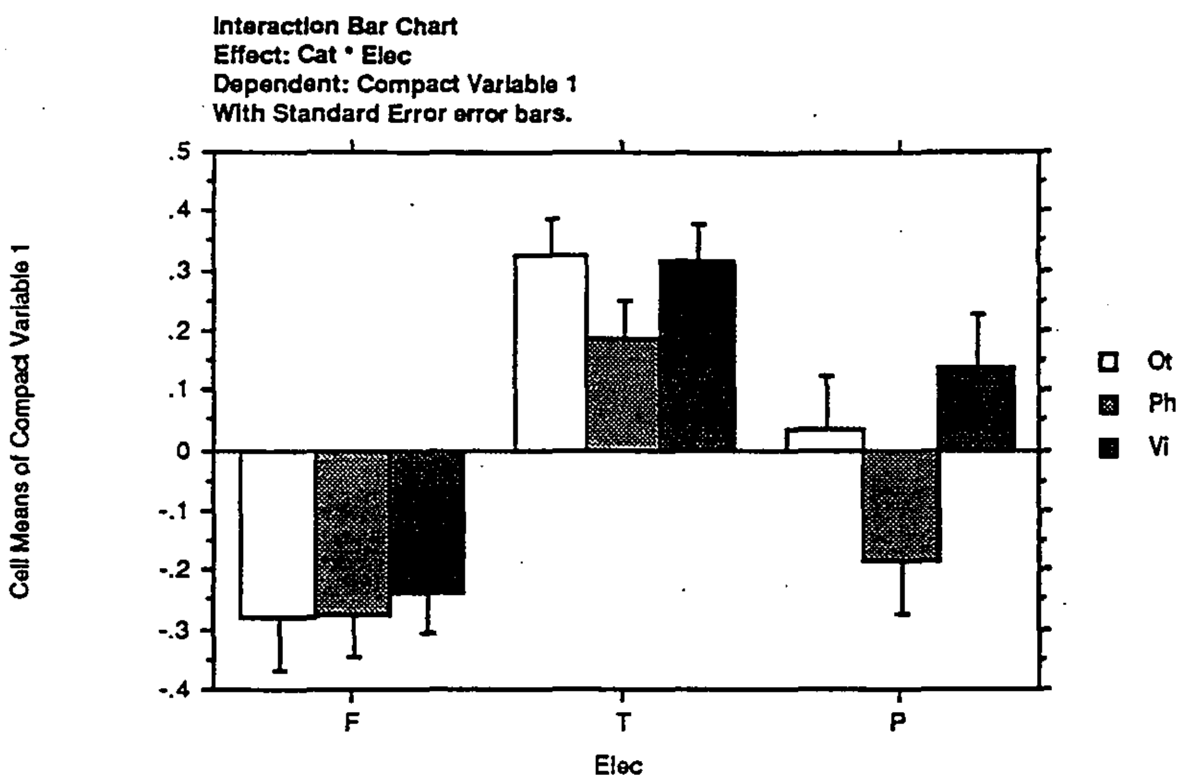
Testing began after each child was given instructions for the tasks. Children then circled the correct word from the two choices. During this time, the probe stimuli were presented and ERPs were simultaneously recorded. The auditory stimuli were presented at an intensity level of 75 dB SPL(A). During the testing, the EEGs were amplified 10,000 times using Techtronix differential amplifiers (AM 502) with low and high bandpass filter settings of .1 and 30 Hz, respectively.

Analyses

Artifact rejection (an artifact was defined as as a shift in the voltage level of 100 microvolts) was conducted on the digitized ERPs to eliminate any data which may have been contaminated by muscle movement or eye blinks during testing. Next, the brainwaves were input into a principal components analysis (PCA). The factor scores derived by the PCA were then input to an analysis of variance (ANOVA). Greenhouse-Geisser correctionswere used for all effects. In this study, there were three types of tasks (phonological, orthographic, and visual) and three electode sites (frontal, temporal, and parietal) across two hemispheres (left and right). The ANOVA design for this study, thus, was a Task (3) x Electrodes (3) x Hemisphere (2) with repeated measures for all factors. Although other methods exist to analyze ERP data, this multivariate system of analysis has proven in previous studies to provide the most consistent results (Brown, Marsh, & Smith, 1979; R.M. Chapman, McCrary, Bragdon, & J.A. Chapman, 1979; Donchin, Tueting, Ritter, Kutas, & Heffley, 1975; Gefler, 1987; Molfese, 1978a, 1978b; Molfese & Molfese, 1979, 1980, 1985; Ruchkin, Sutton, Munson, Silver, & Macar, 1981; Segalowitz & Cohen, 1989).

Results

Our hypothesis was that ERPs could discriminate between the three tasks. Of the four factors derived by the PCA and submitted to the ANOVA, only Factor 3 showed task-related effects. Here, a Task x Electrode interaction, $F(4,332)=2.95$, $p<.027$, indicated that at the temporal electrode sites over both hemispheres, ERPs responded differently to the phonological versus orthographic tasks, $F(1,332)=4.52$, $p<.04$. However, ERPs did not discriminate between phonological versus visual tasks, $F(1,332)=3.97$, $p<.053$, or between orthographic and visual tasks, $F(1,332)=.018$, $p<.86$. At the parietal sites, however, ERPs did discriminate orthographic from phonological tasks, $F(1,332)=11.38$, $p<.0015$ and also phonological from visual tasks, $F(1,332)=24.89$, $p<.0001$. However, even at this location ERPs failed to discriminate orthographic from visual tasks, $F(1,332)=2.61$, $p<.11$. These effects are illustrated in figure 1 which depicts mean amplitudes of the ERPs at the three electrode sites for each of the three tasks.


Interaction Bar Chart
Effect: Cat * Elec
Dependent: Compact Variable 1
With Standard Error error bars.
Cell Means of Compact Variable 1
.5
.4
.3
.2
.1
0
-.1
-.2
-.3
-.4
F
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Elec
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Discussion

Our first hypothesis that phonological measures will be discriminated more readily from visual or orthographic tasks was not entirely supported. This may be in part due to confounds between the visual and orthographic tasks. For instance, since the orthographic task asks subjects to choose between a real and a non-word, spelling skills are necessary to perform well on this task. Moreover, the visual task is also a spelling task, therefore, both of these tasks may be tapping into the same abilities.

Our second hypothesis says that ERPs recorded from the temporal lobe of the brain would best discriminate phonological tasks from the other tasks, however, this was not entirely supported. This may be due to the indirect nature of the probe task. Moreover, since no significant differences between hemispheres were found this may have confounded our results.

Another surprising finding in our study was that there were no significant laterality effects. This was surprising since Molfese et al. (1995) found processing differences between the left and right hemispheres in a study of eight adults. Clearly there are differences between the way children and adults process language information. In future studies it might be interesting to follow children from this cohort into adulthood to monitor changes in lateral language processing.

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