Semantically Based Lexical Processing Yields Unique Topographic Contributions to the Speech Bereitschaftspotential

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SEMANTICALLY BASED LEXICAL PROCESSING YIELDS UNIQUE TOPOGRAPHIC CONTRIBUTIONS TO THE SPEECH BEREITSCHAFTSPOTENTIAL

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(ABSTRACT)

The Bereitschaftspotential (BP) is an event related potential believed to reflect motor planning and preparedness. Although the relationship between the BP and volitional movements of the distal limbs is well established, studies of the BP and speech have produced inconclusive findings. The most heavily debated of these findings were reports of left lateralized hemispheric asymmetry in the BP topography, shortly before speech onset. Several researchers argued that these shifts were artifacts produced by movements of the articulatory muscles. However, methodological differences between the studies could also explain why the asymmetry was not always found. In the present study it was proposed that articulatory complexity and semantic processing each contribute to observed variations in the speech BP topography. Eighteen healthy volunteers performed 3 speech tasks, designed to distinguish semantic and articulatory contributions to the BP topography. The findings suggested that articulatory complexity and semantic processing each uniquely contribute to the frontolateral and medial BP topographic distribution. The present study also introduced the use of Doppler imaging of the tongue as a means of eliminating potential artifactual tongue movements from the speech BP.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Semantically Based Lexical Processing Yields Unique Topographic Contributions to the Speech Bereitschaftspotential

Introduction and Literature Review

Although the electrophysiological events preceding distal limb movements have been widely investigated, the morphology of these phenomena prior to overt speech movements has received modest attention and remains inconclusive. Wohlert (1993) proposed that the Motor Related Cortical Potential (MRCP) associated with speech could possibly serve as a diagnostic tool for speech related language deficits. Further, the ability to track changes in the characteristics of speech MRCP could enhance understanding of the mechanisms behind recovery and compensation of language function following brain traumas such as stroke. Some researchers have investigated the topography and morphology of the components of the speech MRCP (Brooker & Donald 1980; Deecke, Engel, Lang, & Kornhuber, 1986; Empson, 1982; Grabow & Elliot, 1974; McAdam & Whitaker, 1971; Morrell & Huntington, 1972; Wohlert 1993; Szirtes & Vaughan, 1977); however their findings remain inconsistent and the relationship of these potentials to the planning, formulation, and cognitive/linguistic properties of speech have yet to be determined. This lack of consensus partially stems from slight

variations in the methodologies used by previous researchers. Although, contamination from speech muscle artifacts seems to be the primary source of confusion regarding these potentials. The purpose of the present study was to determine if aspects of spoken language, outside the realm of motor planning, contribute to variations in the speech Bereitschaftspotential, the most closely examined component of the MRCP. Tasks were designed in order to discern effects attributable to variations in utterance complexity from those related to linguistic operations, more specifically, semantic processing. It was anticipated that the methodological improvements, implemented in the present study, would resolved many of the problems faced by previous researchers.

The Bereitschaftspotential Prior to Distal Limb Movement

The Bereitschaftspotential (BP) has been the most extensively studied component of the MRCP. Characterized by Kornhuber and Deecke (1965), the BP was a slow, negative cortical potential which preceded distal limb movements by approximately 1s. A classic example of the paradigm eliciting the BP was demonstrated in a study of finger movement by Deecke, Grozinger, and Kornhuber (1976). Electroencephalographic (EEG) data were recorded from the frontal, central, and parietal

regions of the scalp. In order to determine the onset of finger movement, the electromyogram (EMG) was recorded from the surface of the arm, above the digitorum communis muscle. Participants were trained to perform sudden, rapid flexions of the right index finger from a resting state in which the muscles of the hand and arm were completely relaxed, while allowing 3 to 4 seconds to elapse between each finger movement. Data recorded from 1.5 seconds preceding the movements to 500ms after movement onset were examined. Epochs of EEG data were time locked to the onset of the EMG signal and averaged, to produce event related potentials (ERP).

The average onset of the BP was 750ms prior to the EMG trigger, with a symmetrical topographic distribution across the central and parietal regions of the scalp. However, the anterior morphology of the potential was variable between participants, with some participants showing a positive deflection at frontal sites, while in others no shift in electrical potential was present. On average, the maximal negative amplitude was recorded near the vertex (-5.3 μV). At approximately 400ms prior to the onset of finger movement, the BP distribution became slightly asymmetrical, with the greatest negative amplitude residing over the central scalp region contralateral to the finger movement.

This hemispheric lateralization became statistically significant within the last 150ms prior to EMG onset. The BP over the parietal region of the scalp remained bilaterally symmetrical, however.

Other notable MRCP were also present prior to muscle movement. A positive deflection, with a bilaterally symmetrical distribution over the precentral and midparietal portions of the scalp appeared approximately 80 to 90ms prior to the EMG trigger. This component, which was referred to as the pre-movement positivity (PMP), was more variable than the BP, only appearing in a few of the participants' averaged records. A third component partially overlapped with EMG onset. Described as the motor potential, this component was present over the contralateral precentral cortex.

Deecke and colleagues (Deecke, Engel, Lang, & Kornhuber, 1986) hypothesized that the scalp recorded BP may have been the result of a summation of excitatory post-synaptic potentials from cells within the motor, supplementary motor and parietal regions of the cortex. They proposed that the early, bilaterally symmetrical portion of the BP was generated in the supplementary motor cortex (SMA), due to its symmetrical distribution and its midline, maximum amplitude near the vertex of the scalp. The

late, asymmetrical amplitude increase was interpreted as involvement of the contralateral primary motor cortex in the final stages of preparation and initiation of motor movement. The components closer in proximity to the onset of EMG were proposed to be more closely related to the final motor command. Similar conclusions were formed by Shibasaki, Barrett, Halliday and Halliday (1980) and Tarkka and Hallett (1991). Invasive electrophysiological recordings from animal studies corroborated this proposed two source hypothesis. For example, Neafsey, Hull, and Buchwald (1978) found that pyramidal neurons in the lateral and medial cortex remodulate their firing rates approximately 500ms prior to movement onset in cats. Neurons firing prior to 500ms premovement were located exclusively in the medial region.

Early Investigations of the Bereitschaftspotential Prior to Speech

The findings from speech BP studies have been more ambiguous. As with distal limb movement, the BP has been the most closely examined of the MRCP components. Although the onset of the BP has been consistently reported at much earlier latencies than those associated with other motor behaviors, both the topography and morphology of the speech BP have been shown to vary considerably among studies. Wohlert (1993), for example,

found no evidence of BP lateralization prior to speech, while Deecke, Engle, Lang, and Kornhuber (1986) found that the BP lateralized to the left precentral cortex just prior to speech onset, in a similar manner as prior to movement of digits from the right hand. Further, this asymmetry extended to the anterior, in the scalp region overlying Broca's area. The issue of laterality has dominated the literature on the topic of speech BP and evidence from multiple studies lent support to both the lateralized distribution found by Deecke (Empson, 1982; McAdam & Whitaker, 1971) and the symmetrical distribution found by Wohlert (Brooker & Donald, 1980; Grabow & Elliot, 1974; Morrell & Huntington, 1972).

Neuroimaging Studies of Cortical Activity Prior to Speech

Left hemisphere laterality of language function in right handed individuals has been widely accepted, and a plethora of evidence exists supporting not only anatomical differences in left hemisphere structures thought to support language (Geschwind 1984; Damasio & Geschwind 1984), but also functional differences between these structures and their right hemisphere homologs (Blank, Scott, Murphy, Warburton, & Wise, 2002; Buckner, Raichle, & Petersen, 1995). Could a similar consensus be drawn regarding pre-speech planning? Some evidence has suggested

hemispheric laterality in the premotor areas of the cortex, prior to speech. Studies of patients with lesions in the supplementary motor area (SMA), without damage to the classic language areas, have shown that unilateral lesions to the left SMA typically produced partial mutism (Goldberg, 1985). Patients with this syndrome lacked spontaneous speech, but retained the ability to repeat short phrases or in some instances responded to direct questions with brief, unelaborated responses. Patients typically recovered spontaneous speech if the SMA of the nondominant hemisphere was undamaged, suggesting that the contralateral SMA could compensate for the damaged area. Lateral premotor areas have also shown functional asymmetries prior to speech. Using Positron Emission Tomography (PET) Petersen, Fox, Posner, Mintum, and Raichle (1988) found greater activation over the left inferior prefrontal cortex than the right, during speech tasks. Interestingly, this asymmetry was greater for a verb generation task when compared to a single word repetition task. Functional asymmetries at the level of the primary motor (PM) cortex were also observed prior to speech. In an fMRI study by Wildgruber, Ackermann, Klose, Kardatzki, and Grodd (1996), functional activation patterns were compared between non-speech tongue movement and recitation of the names of the month. Tongue

movement produced a bilateral hemodynamic response in the orofacial area of the primary motor area. The speech condition produced activation in the same cortical region; however activation in the left motor area was significantly greater than in the right. Interestingly, the opposite was found when the participants were asked to sing the melody of a familiar song.

Factors leading to Conflicting Speech Related BP Findings

Considering this evidence, it does appear that motor planning and control of speech are to some extent cortically left lateralized. It is puzzling then that the findings from speech BP studies have failed to show consistent evidence of lateralization for speech motor planning. A review of the relevant literature revealed considerable methodological variability in the early speech BP studies. Differences in factors such as electrode montage, quantification of the electrophysiological signals, task, and control for EMG artifact contamination might partially explain their contrasting findings.

Standardization of electrode placement is critical when comparing the results of electrophysiological studies. Without a detailed description of the precise placement of electrodes or indication of the coordinate system used, caution should be taken when drawing conclusions based across the findings of

multiple studies. Morrell and Huntington (1972), recorded the speech BP from a variety of scalp sites, and found no evidence of left hemisphere lateralization. Unfortunately, with the exception of indicating that the electrodes were affixed to the scalp, the authors provided no information as to the location of their recording sites. Thus it is difficult to compare their findings to those of Deecke et al. (1986), who used the standardized 10/20 coordinate system (Jasper, 1958). Furthermore, while many studies did report the locations of their electrodes, the sites chosen by the authors were dissimilar to those of previous studies. Wohlert (1993) for example recorded from three central electrode sites, approximately overlying the left and right primary motor cortices and SMA. Although these locations did conformed to the 10-20 system, a standard adopted by the majority of electrophysiologists, they did not include sites over the left and right inferior frontal cortex, the region at which Deecke and colleagues found their strongest evidence of left lateralization in the speech BP.

Variations in signal processing methods between studies have added further ambiguity to the speech BP. Differences in baseline interval, epoch length, and amplitude measurements have all led to sharply contrasting findings. Picton, Bentin, Berg,

Donchin, Hillyard, Johnson, Miller, Ritter, Ruchkin, Rugg, and Taylor (2000) noted that the selection of an appropriate baseline interval and epoch length can be particularly problematic for response locked averages, such as the BP. Because the slow negative shift in amplitude associated with motor planning may in some cases precede movement onset by 2 or more seconds, it can be difficult to determine an appropriate baseline or interval length. These two factors varied substantially between the speech BP studies. For example, in the study by Deecke et al., (1986) the interval was set for 2000ms premovement onset, While Wohlert (1993) chose to use 1500ms intervals. Both studies selected 500ms baselines; however, due to the shorter interval used by Wohlert, the baseline in the later of the two studies was 500ms closer to the onset of speech. The studies by Deecke et al., Wohlert, and many others also differed in terms of their means of quantifying the BP signal. Deecke took the average amplitude from the final 100ms preceding the onset of speech while Wohlert defined the BP as the amplitude at 100ms prespeech. Direct comparison of the findings from these studies is problematic for several reasons. First, the baseline interval in an ERP study serves as a zero point, from which the amplitudes of ERP components are measured.

Although both studies chose to use the earliest 500ms of the BP interval as a baseline, Wohlert's baseline interval occurred within the time period Deecke used to define the speech BP. If the negative shift in amplitude associated with the BP was already present during this interval, measurements of peak amplitude negativity would be greatly attenuated. Thus, the maximum amplitude measurements would be smaller in Wohlert's study than those of Deecke's. Secondly, Wohlert and Deecke chose distinctly different methods of quantifying their amplitude measurements. Deecke chose to use the averaged amplitude from an interval preceding the onset of speech. Wohlert chose fixed points from which to measure the amplitude. If slight perturbations were present in Wohlert's ERP signals, then it is possible that a slight, momentary change in amplitude could have influences peak amplitude measurements. Thus, this method had the potential to introduce error into Wohlert's measurement, making her findings difficult to compare to Deecke's. These same two quantification differences are present between most of the research on speech BP (Brooker & Donald 1980; Empson, 1982; Grabow & Elliot, 1974; McAdam & Whitaker, 1971; Morrell & Huntington, 1972; Szirtes & Vaughan, 1977), making it difficult to draw conclusions from a comparison of any of these studies.

Even those studies in which the researchers specifically stated that they had hoped to replicate the methodology of previous studies failed to define their amplitude measurements within the constraints of their predecessors. For example, Morrell and Huntington (1972) stated that they replicated the methodology used by McAdam and Whitaker (1971), but then used shorter baseline and BP intervals.

Task differences between the studies were a further concern. In the study by Deecke and colleagues (1986), participants performed a verbal fluency task, in which they were asked to generate words beginning with |P| and a vowel sound. Participants were instructed not to repeat any of the words, and to allow an irregular interval of 4 to 12s to elapse between each utterance. In contrast, Wohlert's participants were asked to repeat the word |Pool|, with an 8 to 12 second pause between utterances. It could be argued that the tasks performed in these experiments varied on a number of dimensions. Most importantly, these tasks differed in the extent to which they called upon lexical decision making. Both tasks require the retrieval of sets of articulatory gestures, required to perform the specific speech utterances. However, in order to perform Deecke's task, the participants had to perform a lexical search and retrieve

appropriate words based on their phonological structure prior to the planning of the actual speech utterance. Possibly, performance of this lexical search resulted in a greater utilization of left hemisphere language related cortical structures than the single word repetition, thus producing a higher amplitude BP over the left hemisphere. McAdam and Whitaker (1971) used a task similar to that of Deecke et al., (1986). Participants were asked to generate words that began with |P| and |K|. These researchers also found left lateralization of the speech BP at scalp sites overlying Brocca's area. In contrast Grabow and Elliot (1974) and Morrell and Huntington (1972) found no evidence of laterality over Brocca's area, or at any other scalp sites. However, the participants in each of these studies performed word repetition tasks, similar to the task used by Wohlert. There was however one word generation study in which the BP was concluded to be symmetrical in distribution preceding speech. Brooker and Donald (1980), instructed their participants to generate words beginning with |P| and |K|. They did find evidence of lateralization over the left inferior frontal lobe; however, they argued that the averaged signal was highly correlated with

EMG from facial electrode sites, and was therefore unlikely to have originated in the cortex.

Finally, it was also possible that the findings from some of the studies were heavily influenced by muscle artifacts produced by movement of the articulators. Several researchers have questioned the feasibility of recording the speech BP. They argued that the presence of EMG artifacts from the tongue, lips, cheeks and other articulators necessary for speech production made it impossible to accurately describe speech related potentials (Brooker & Donald, 1980; Morrell & Huntington, 1972). Although artifact contamination had the potential of occurring anywhere within the recording interval, its impact was most closely investigated within the last few hundred milliseconds prior to speech onset. Grozinger, Kornhuber, and Kriebel (1975) found that EMG onset from the orbicularis oris could in some cases precede the acoustic signal of speech by up to 500ms. This casts doubts on the findings of several researchers who used the acoustic signal as a marker for the onset of speech. Could EMG contamination from the lips have produced the observed hemispheric asymmetries? McAdam and Whitaker (1971) used the acoustic signal to indicate the onset of speech and found a left lateralization in the BP. However, Morrell and Huntington (1972)

and Grabow and Elliot (1974) also made use of the acoustic signal and found no evidence of lateralization. Brooker and Donald (1980) also used the acoustic signal as a marker, but additionally measured EMG over the orbicularis oris. Noting that EMG from the lips occurred prior to the acoustic signal, they chose to measure the BP just prior to the EMG burst. They did find a left lateralization in the BP, but also claimed that this signal showed a high correlation with EMG from other facial recording sites. More recent studies abandoned the use of the acoustic signal as a marker for speech onset. Both Deecke et al. (1986) and Wohlert (1993) used the onset of EMG from the orbicularis oris to mark the onset of speech. However, their findings regarding BP lateralization still contrasted with one another.

In addition to the lips, the tongue was also suspected of introducing EMG contamination into speech BP findings. Szirtes and Vaughan (1977) proposed that movements of the tongue were the most likely source of hemispheric asymmetries associated with speech. To test this hypothesis, the authors compared two tongue movement tasks to a speech tasks. They found striking similarities in the BP between tongue movements and the articulation of words conforming to specific phonologic patterns.

Anterior and posterior tongue movements elicited BP waveforms which were morphologically similar to those recorded prior to the articulation of words starting with the letter |I|. Vertical tongue movements produced waveforms that were similar to words that began with the letter |E|. Further, horizontal tongue movements to the left and right produced hemispheric asymmetries in the BP topography. Szirtes and Vaughan concluded that tongue movements were the most likely source of the hemispheric asymmetries observed by other researchers studying prespeech motor planning. However, it should be noted that the acoustic signal served as the marker for determining the onset of speech. Thus, it was probable that the data was also heavily contaminated with EMG from the lips. Furthermore, tongue deviations to the left and right during normal speech are extremely unlikely to occur (Dogil, 2002; McArdle & Braun, unpublished data set, 2003).

In summary, the contradictory findings from studies of speech BP were possibly due to methodological variability. Tasks, recording sites, methods of quantification, and control for artifact contamination were not held consistent among any of these studies. This led to controversy over the very nature of speech motor planning, particularly since methodologies with

poorer temporal resolutions (i.e. Pet and MRI) had produced evidence supporting left cortical dominance for the motoric planning of speech. In addition, the feasibility of studying prespeech motor planning with electrophysiological measurements became questionable. Several researchers concluded that facial EMG contributions to any scalp recorded potentials were unavoidable, and therefore discounted the BP as a viable measurement of speech motor planning.

Factors Affecting the Medial BP Topography

As previously mentioned, the lateral distribution appeared to be the central focus of controversy in the speech BP literature. However, BP findings from studies of distal limb movements suggest a second region were variations should be anticipated in the speech BP topography. In a study by Schreiber, Lang, Lang, Kornhuber, Heise, Keidel, Deecke, and Kornhuber (1983) the BP was recorded prior to a writing task, two drawing tasks, and simple finger flexions. It was found that the writing and drawing tasks resulting in a shift in the maximum midline BP amplitude from the vertex (CZ) to a slightly more anterior electrode site (FCZ). The authors interpreted this anterior shift as the recruitment on frontal cortical regions for the tasks requiring more complex sequencing of motor movements. A

more anterior midline BP topography was also shown for speech. Deecke and colleagues (1986) demonstrated that the BP, prior to speech, was significantly greater in amplitude over the frontocentral site (FCZ) in comparison to the vertex (CZ), where simple finger movements typically produced the highest midline amplitude. Unfortunately, only a single speech task was included in the study and no other speech BP studies included midline recording sites anterior to the vertex. Thus it could not be determined whether the anterior shift was a general characteristic of speech or related to a more specific characteristic of the speech task (i.e. articulatory complexity or underlying linguistic operations) performed in the study. Some evidence from the neuroimaging literature does suggest that task parameters may affect the midline cortical activity associated with speech. In a review of the findings from PET studies, by Picard and Strick (1996), it was concluded that task complexity played a significant role in the pattern of medial cortical activation. Simple tasks, such as repetitive finger movements, produced activation in the caudal portion of the medial surface of area 6 (SMA proper). More complex tasks, playing a piano score for example, resulted in activation toward the more rostal section of this area, most recently referred to

as pre-SMA. Complex tasks also produced activation in the rostal section of the cingulate motor area (CMA). Similarly single word repetition resulted in activations within SMA proper, while verb generation, a relatively more complex task, elicited activations in both the pre-SMA and CMA. Unfortunately, Picard and Strick (1996) made no distinction between motorically and cognitively complex tasks in their meta-analysis. For example, a verbal fluency task necessitates the generation of both complex articulatory patterns and the utilization of higher order cognitive/linguistic operations. Thus further research is warranted in order to determine the aspects of speech which lead to changes in midline BP cortical activity.

Purpose and Hypotheses

The purpose of the present study was to disambiguate cognitive and articulatory contributions to the morphology of the speech related BP. The effects of motor and cognitive complexity are well established for the BP preceding distal limb movement. For example, Kristeva (1984) compared BP waveforms recorded prior to the performance of a complex piano melody to waveforms recorded prior to single notes. Greater BP amplitudes and longer latency were reported for the melody task (but see also Schreiber et al., 1983). Cognitive factors, including

attention (Kornhuber & Deecke, 1965) and motivation (McAdam & Seals, 1969) have also been shown to affect the BP prior to movements of the limbs.

Some evidence suggested that motoric (i.e. articulatory) and cognitive complexity could also influence the amplitude of the speech derived BP. For example, studies in which the participants were instructed to repeat a single word, with a relatively simplistic articulatory pattern (Grabow & Elliot, 1974; Morrell & Huntington, 1972; Wohlert, 1993) reported BP averages of lower mean amplitude than studies which used varied and thus somewhat more complex utterances (Brooker & Donald 1980; Deecke, Engel, Lang, & Kornhuber, 1986; Empson, 1982; McAdam & Whitaker, 1971). Task complexity from a cognitive standpoint may also have influence BP amplitudes between these tasks. In order to achieve variability in articulatory output, the studies which required participants to select different utterances on each trial incorporated lexical tasks. For example, McAdam and Whitaker's participants were instructed to select words based on a phonological criterion (i.e. words three syllables in length, beginning with a specific consonant). As previously mentioned the majority of the studies which adopted lexical tasks found left lateralized asymmetries in the BP distribution. It should

be noted however that motor and cognitive complexity were not independently manipulated in any of the previous speech BP studies. Single word repetition tasks were simplistic in terms of both motor and cognitive complexity, while the tasks in which the articulatory pattern varied between trials were complex both in terms of necessary cognitive processes and motor control. Thus, in order to accurately determine the individual contributions of each factor, at least three types of speech task should be selected: 1. a task in which cognitive and articulatory control are simplistic, 2. a task which calls upon complex cognitive processing and complex articulatory control, and 3. one which is cognitively simplistic yet requires complex articulatory control.

Tasks in the present study were selected with this reasoning in mind. Tasks include: Simple Speech- Similar to the speech task used by Wohlert (1993), participants repeated a single, phonetically simplistic, word, “Pool”. Verbal Fluency- nouns were generated by participants based on pre-selected supraordinate categories. And Word Repetition- words generated by the individual participants during the Verbal Fluency task were presented in serial order, and participants were asked to repeat them.

The Simple Speech task involved voluntary initiation and execution of coarticulated movements of lips, tongue, jaw and larynx. However these movements required minimal articulatory control since the same invariable phonetic pattern were repeated on each trial. Verbal Fluency, on the other hand involved more complex motor activity (i.e. - production of words with complex phonological and phonetic structure) and higher level cognitive processes, such as a semantics based lexical search and selection (i.e. - access and retrieval of appropriate items from the mental lexicon). Word Repetition, repetition of the words generated in Verbal Fluency task, involved complex motor control but not lexical access. Therefore, a comparison of Word Repetition and Simple Speech was expected to highlight changes in the BP due to motor complexity. The Comparison of Verbal Fluency and Word repetition was expected to highlight any additional changes due to high level cognitive/linguistic processing. A more thorough description of these tasks and the methods by which they were compared can be found in the method section.

Variations in BP morphology between tasks were anticipated along the midline, frontal and precentral scalp regions. Proposed task related regional variations in the BP waveform

were presumed to reflect differential involvement of cortical regions in the planning of articulatory gestures and in the processing of cognitive/linguistic information.

Hypothesized Scalp Midline Amplitude Differences

It was hypothesized that the maximum midline amplitude would show a shift to the anterior for the Word Repetition and Verbal Fluency tasks, when compared to Simple Speech. Moreover, it was anticipated that the anterior midline BP would be higher in amplitude for Verbal Fluency when compared to Word Repetition. Findings from both PET and electrophysiological studies supported this hypothesis. Picard and Strick (1996) noted that single word repetition resulted in increased rCBF in the SMA proper, while tasks requiring greater articulatory control were related to rCBF increase in the pre-SMA and rostal cingulate motor cortex. Furthermore, Deecke et al., (1986) found maximal midline BP amplitude at electrode FCz when participants performed a speech task in which spoken responses varied between trials. As previously noted, FCz was slightly anterior to the electrode site where the maximum BP amplitude was typically recorded prior to limb movements. Both findings suggested that motoric and possibly more cognitively demanding speech tasks

required the recruitment of medial wall regions, anterior to SMA proper.

Hypothesized Variations in BP Left Lateralization

It was hypothesized that BP amplitude would show a left hemisphere lateralization over the precentral region of the scalp for all three speech tasks. However, it was expected that Word Repetition would show greater laterality than Simple Speech. Precentral amplitude lateralization was hypothesized to be even greater for Verbal Fluency, when compared to Word Repetition. Furthermore, a comparison Verbal Fluency to Word Repetition was hypothesized to show BP left lateralization extending into the frontal scalp region. A comparison of the findings from previous speech BP studies offered some support of this hypothesis. Studies more frequently found left lateralization of the pre-centrally distributed BP when their tasks required participants to generate words (Brooker & Donald 1980; Deecke, Engel, Lang, & Kornhuber, 1986; Empson, 1982; McAdam & Whitaker, 1971). Deecke et al (1986) found this left laterality also extended into the frontal scalp region. Conversely, symmetry in the BP generally preceded tasks in which single words were repeated (Brooker & Donald 1980; Grabow & Elliot, 1974; Morrell & Huntington, 1972; Wohlert, 1993). Greater left laterality for cognitively complex

speech tasks was also supported by the neuroimaging literature. Indefrey and Levelt (2000) suggested that regions of the left lateral frontal cortex played an executive role in tasks which required the retrieval of concept based information from memory, such as verbal fluency tasks.

While the spatial resolution of ERP measurements, such as the BP were poor in comparison to PET and MRI, inferences could still be made as to the cortical origins of these electrophysiological signals based on variations in their amplitude and morphology across the scalp. Furthermore, the ERP offered greater temporal resolution, which was unachievable with PET or fMRI. Thus, it was possible to chronologically measure the rapid changes in electro-cortical signals, which were believed to be related to stages of information processing and response preparation. Taking the temporal benefits into consideration, ERP measurements were expected to yield important information regarding the relationship between sequential activations of specific cortical regions and cognitive processes, such as linguistic planning and motor preparation.

If cognitive and motor processes did in fact produce differential effects on the BP morphology, knowledge of the dynamics of this phenomenon could then be applied to future

studies of trauma related language deficits. For example, changes in the morphology of the BP could be tracked as patients with aphasia progressively recover language function. Mechanisms of compensation for cortical damage have been shown to vary among patients and studies have demonstrated that some patterns of compensation were associated with better prognoses than others (Karbe, Thiel, Weber-Luxenburger, Herholz, Kessler, & Heiss, 1998). Characteristic BP changes could serve as an evaluative tool for determining how individual brains compensate over time for damaged tissue.

Methodological Advancements

Speech related electrophysiological data were highly susceptible to EMG contamination, and as noted previously, some researchers had entirely dismissed the speech BP, claiming that the phenomenon was the product of EMG volume conduction and thus artifactual (Szirtes & Vaughan, 1977). Given the close proximity of the articulatory muscles to the scalp, this suspicion was somewhat understandable. In many cases, the electrical signals generated by muscle tissue have ranged hundreds of micro-volts beyond signals generated by the brain. These signals could easily mask or be mistaken for legitimate cortically based signals. Possibly, due to this confound, investigations of the

speech related BP were largely abandoned. However, considering the potential efficacy of a reliable index of linguistic and speech motor planning, further efforts to isolate the speech BP were warranted.

Before the speech BP could be studied without bias, a necessary first step was to develop an effective means of articulatory artifact exclusion or control. While many methods were available for removing EMG from electrophysiological data (e.g. visual inspection and removal, independent component analysis, or filtration), the simplest and least disputed solution was to avoid contamination in the first place. Articulator movements were obviously inherent to spoken language, however, the BP waveform, by definition preceded movement. Thus, one possible means of avoiding contamination was to identify on a trial by trial basis, the precise onset of speech related EMG. Data beyond this time point would then be discarded, or at the least, regarded with more caution.

Event related potentials, such as the BP were derived by averaging multiple sweeps of EEG data. These sweeps were time-locked to an event, such as a stimulus or measured response from the participant. In principle this process served two functions. First, the contributions of unrelated EEG signals which were

typically out of phase with the event of interest were reduced. Second, through this reduction, averaging also served to accentuate the signals associated with the event. For example, the BP associated with limb movement was derived by recording multiple sweeps of EEG over the course of a finger movement task. The onset of EMG, which was simultaneously recorded, typically served as the time-locking event or trigger for EEG averaging.

Many of the early speech related BP studies deviated from this methodological practice (McAdam & Whitaker, 1971; Grabow & Elliot, 1974; Morrell & Huntington, 1972; Brooker & Donald 1980; Empson, 1982; Szirtes & Vaughan, 1977) and chose to use the onset of the acoustic signal from speech as the time locking-event. As their rationale it was argued that the acoustic signal was the most reliable and invariant indication of speech onset, and produced the clearest averaged signals. Unfortunately though, the practice of using the acoustic signal as a time locking event was problematic. Szirtes and Vaughan (1977) reported that the EMG signal at the lips often preceded phonation by 200ms or more and recent findings suggest that lip recorded EMG may in some cases precede the acoustic signal by 800ms or possibly more (McArdle & Braun, unpublished data set, 2003). Thus, speech BP

time locked to the onset of phonation were likely to contain heavy EMG contamination.

Later studies by Deecke et al. (1986) and Wohlert (1993) were able to avoid lip EMG contamination by selecting the onset of lip muscle movement as the time lock. However, the tongue was also been implicated as a potential source of EMG contamination. Szirtes and Vaughan (1977) compared the BP derived from various types of tongue movements and spoken utterances and noted that characteristics such as waveform polarity and their topographic distribution across the scalp were highly dependent on the direction of tongue movement. Tongue deviations to the left or right for example, produced lateralization effects over the temporal scalp region.

Attempts to reduce the contributions of tongue movement artifacts were made by several studies (Deecke, 1996; Wohlert, 1993; McAdam & Whitaker, 1971; Morrell & Huntington, 1972; Brooker & Donald, 1980). Primarily, their strategy was to reduce tongue movements by constraining the phonological structure of the words spoken by their participants. For example, Wohlert's (1993) participants were limited to a single utterance; the word |Pool|, which was believed to require very minimal tongue movements. Participants were also asked to de-emphasize the |l|

sound in the word, in order to further decrease the involvement of the tongue. In other cases, researchers instructed participants to limit spoken responses to words beginning with specific consonants/vowel combinations (Deecke, 1986; McAdam & Whitaker, 1971; Morrell & Huntington, 1972; Brooker & Donald 1980). For example Deecke and colleagues required participants to generate words beginning with phonemes composed of the consonant |P| and vowel sound, reasoning that these words would involve relatively few early tongue movements.

While limiting the phonological structure of words may have offer some reduction in tongue movement, there were several notable problems with this strategies. First, as demonstrated by Szirtes and Vaughan (1977) characteristics, such as the polarity and scalp distribution, of the BP varied as a function of the speech utterances phonological composition. Dramatic differences were shown between words beginning with several different phonemes. In fact words that began with some phonemes were found to be associated with positive potential rather than the more commonly reported slow negative shift. If these differences in waveform morphology were due to phoneme specific articulatory contamination, as was concluded by Szirtes and Vaughan, then it should be anticipated that restricting the phonological pattern

of spoken response, would increase the likelihood of any one given pattern of articulator related artifact influencing the topography of the speech BP. Secondly, while restricting the set of spoken responses may have somewhat reduce tongue movement contamination; no practical means of measuring tongue movements were used in any of the studies cited. The effectiveness of this strategy could therefore not be determined. Preparatory positioning of the tongue has been demonstrated to occur in some cases during the articulation of |P| and |B| consonant-vowel phonemes in preparation for later articulatory gestures (Tuller & Kelso, 1984). Furthermore, pronunciations of phonemes beginning with |P| still required some tongue movement. For example, during typical speech the tip of the tongue was lowered and the back of the tongue was raised during the pronunciation of the phoneme |Po|.

In addition to the potential difficulties associated with the practice of constraining phonemic variability as a means of reducing EMG contamination it could also be argued that this practice somewhat reduced the ecological validity of speech BP studies. Experiments designed for the expressed purpose of studying aspects of typical human behavior should, as closely as possible, approximate the conditions and variables associated

with the behavior. Thus, tasks intended for the study of language should bear some similarity to normal communications. Single words are almost never habitually repeated, nor are we typically required to search our mental lexicon for words of specific phonemic structures.

To summarize, articulatory artifacts could be effectively excluded from the speech BP by time locking BP averaging to the precise onset of speech related movement. However, many different articulatory muscles were involved in speech movements and it appeared that their pattern of interaction was highly dependent on the phonological structure of individual utterances. Thus, multiple articulators should be monitored in order to determine the onset latency at which speech muscle movements begin.

In preparation for the current study, pilot data were collected in order to determine effective means of measuring the onset latency of articulators suspected of contributing EMG contamination to the speech BP. The lips and tongue were previously implicated by Szirtes and Vaughan (1977). Another possible source which had gone unmentioned was movements of the glottis. Means of non-invasively monitoring the movements of these three articulators were evaluated during piloting.

While EMG, measured at the vermillion boarder of the upper and lower lips could be monitored with very little difficulty, an effective means of measuring tongue movement was more elusive due to the tongue's enclosure in the oral cavity. Doppler imaging was examined as a means of determining the onset of tongue movement during piloting, and was found to be effective. Finally, the electroglottogram, an index of vocal fold adduction, measurable from the surface of the neck was selected as a means of determining the onset of glottal movements.

In order to test these measurements, several participants were asked to perform a reading task while movements of the lips, tongue, and glottis were synchronously monitored. Single words were presented in serial order and participants were instructed to read each word aloud. Words were selected on the basis of their phonemic structure, in order to ensure representation of word beginning with all valid English phonemes. A visual inspection of the data revealed no cases in which the glottis moved prior to the tongue or lips. Because of this, it was deemed unnecessary to measure vocal fold adduction in the present study. The order of lip and tongue movement was highly variable between utterances. Thus, in order to capture the specific onset of speech muscle movement in the present study,

both measurements were utilized as time-locks for averaging purposes. Epochs in which tongue movement precedes the onset of lip EMG were time locked to the onset of shifts in the Doppler signal and epochs in which the lips move first were time locked to lip movements. It was anticipated that this technique would exclude artifactual contributions of articulatory muscle movements to EEG data within the temporal window in which the speech BP was expected to occur. Thus, the averaged BP recorded in this study was believed to reflect mental processes associated with preparation for speech, rather than a summation of artifact, present in the raw EEG epochs.

Method

Participants

Statistical power was estimated using the Φ^2 calculation described by Keppel (1991) for within subjects designs. The estimate was based on pilot data collected during the Verbal Fluency and Simple Speech task from 6 participants. The mean amplitude of the BP within the time interval of -1000ms to the onset of speech was chosen as the dependent measure. The obtained value of Φ was 1.64. Referring to the Pearson-Hartley chart, it was determined that statistical power approximating .80 could be achieved for tests performed at α

=.05 level with a sample of 20 participants. However, a preliminary analysis conducted with data from 18 participants supported the primary hypotheses. It was therefore decided that no further data were required and recruitment was closed. Participants were recruited from the volunteer pool at the National Institutes of Health (NIH). Other individuals who wished to participate and met the screening criteria were admitted to the NIH clinical center prior to the date of their participation. Newly admitted participants received a neurological evaluation from a licensed neurologist prior to participation. Only individuals with no prior history of or present neurological disorder were asked to participate. All participants were native English speakers. Data included in the analysis were recorded from 8 female and 10 male participants. Prior research had demonstrated morphological changes in a variety of ERP components as a function of age (Onofrj, Iacono, Andreamatteo, & Paci, 2001). Consistent with these findings, the BP amplitude had also shown variations with age. Barrett, Shibasaki, and Neshige (1986) found that both the early and late BP components were greatly attenuated in older participants. In addition, the slight contralateral asymmetry, typical of the late BP prior to limb movement, was not present in many of their

older participants. Thus, in order to avoid age related variations, recruitment was limited to participants between the ages of 18 to 40 years of age. The mean age of the volunteers who participated in the study was 27.5 (SD = 5.86).

Handedness of the participants was assessed using the Edinburgh Inventory (Oldfield, 1971). All were right-handed (mean L.Q. = 94.4, SD = 9.2). All participants reported having no known neurological disorders, and were not taking any psychoactive medications at the time of their participation in the study. Neurological histories were indexed through a standardized questionnaire or through neurological evaluation. It was anticipated that these restrictions would promote neurological homogeneity within the sample. All participants received $150 compensation.

Procedure

Participants were asked to read and sign an informed consent form in the waiting area of the 5th floor outpatient clinic. Participants also completed the Edinburgh Inventory (Oldfield, 1971), a questionnaire designed to assess neurological history, and, if any, the medications the participant was taking at the time of the study. Two volunteers did not meet the criteria for participation in the study, one of

whom indicated a history of left-handedness and the second reported having lost consciousness for more than 5 seconds as the result of a head trauma. These participants were thanked for their time and excluded from the remainder of the study.

Electrophysiological Recording

Prior to scalp electrode application, facial EMG recording sites, the earlobes, and approximate site of the ground electrode were thoroughly cleaned with Nu-prep, exfoliating gel and alcohol pads. Placement of the Cz and FPz electrodes were determined through scalp measurements. Cz was located by determining the point 50% of the distance between the inion and nasion and the left and right preauriculars. Placement of FPz was determined by finding the point 10% of the distance between the nasion and inion. Participants were fitted with a 62 channel electrode cap, conforming to the extended international 10/20 electrode placement system (Neuroscan Labs, 1998). The electrodes attached to the cap were made from sintered silver/silver Chloride and measured 9mm in circumference.

Recordings from the left and right lateral occipital regions of the scalp (O1 and O2) were sacrificed from this study. These amplifier channels were instead used to record other physiological signals (described below).

Two pairs of sintered 9mm bipolar EMG electrodes were applied to sites on the face using double sided adhesive collars. One pair was used to measure the electro-oculogram (EOG) and was placed above and below the left eye. The second pair was used to measure lip EMG. This pair was placed near the vermilion borders of the upper and lower lips, overlying the orbicularis oris.

A syringe with a blunt tip needle was used to apply Quick-Gel, an electrolyte gel designed to improve conduction, between the skin and electrodes. Electrical impedance was maintained below 5K ohms between the ground electrode and all mono and bipolar electrodes.

An Acuson model 128 XP sonograph with a C7 transducer was used to monitor movements of the tongue during performance of the speech tasks. The sonograph was set to pulsed wave Doppler mode. This setting permitted both visual and auditory monitoring of velocity changes in the imaged tissue. The sonograph's transducer was placed between the neck and chin. Adjustments in the placement of the transducer were made so that a full lateral image of the base of the tongue could be viewed on the sonograph's CRT monitor. Signal gain adjustments were made in order to ensure that any lateral or vertical movement of the tongue base produced detectable changes in the amplitude of the

Doppler signal. The participants' spoken responses were recorded with a Sony model ICD-MS1 digital audio recorder. The amplitudes of the Doppler and speech signals were attenuated by a factor of 500, using signal conditioning hardware designed by Randall Pursley.

EEG, EMG, Doppler, and the acoustic speech signal were acquired using two 32-channel Synamp bioamplifiers, built by Neuroscan Labs. The sampling rate was 2000Hz. High rate sampling was necessary in order to accurately record the temporal features of the Doppler and speech signals. The low pass filter was set to 100 Hz for the combined 62 EEG and EMG channels and 500Hz for the Doppler and speech signals. The high pass filter was set to 1Hz for the Doppler, speech, and EMG channels in order to reduce the contributions of DC drift to these signals. No high pass filter was used for the EEG recording.

Data were recorded continuously to the hard drive of a Pentium 4 computer using the EEG acquisition software package written by Neuroscan Labs.

ERP Averaging

ERP averaging was time locked to the onset of the earliest source of articulation related movement on trial by trial bases.

Movement onset was determined using a program included in the BESA electrophysiological data analysis software package, which identified the time points at which specified voltage thresholds had been reached for each of the articulator movement channels. Movement data from the tongue and lips were rectified and smoothed by a factor of 40Hz prior to the identification of movement onset. Due to amplitude variations between participants, voltage thresholds for the lips and tongue were determined individually per participant. Participants' lip and tongue data from each of the three conditions were visual inspected and 20 EMG and Doppler bursts which appeared to typify those recorded from the participant were randomly selected. Amplitudes from the earliest peaks of each burst were then averaged in order to determine voltage threshold. From the 18 participants, the mean EMG and Doppler voltage thresholds were 14.30μV, SD = 1.05 and 168.41, SD = 24.15, respectively. A second inspection of the articulator movement data was performed following trigger placement in order to identify any anomalous, non-speech related markers. For example, intermittent DC corrections within the data sometimes resulted in artifacts which were falsely identified as articulation onsets by the computer program. These were deleted from the recording.

Averaging was performed on raw EEG epochs of 6000ms. Epochs began 3000ms prior to, and ended 3000ms following the onset of articulator movement. Epochs were visually inspected for ocular and speech related muscle artifact. Those determined to contain muscle artifacts preceding speech onset were removed from the analysis. DC offset corrections were performed using the first 500ms of each epoch as a baseline.

Data Quantification

An inspection of pilot data revealed BP morphological characteristics similar to the early, slow BP1 and the steeper BP2, which typically precede limb movements (see Figures 1 and 2). However, the onsets of these components were much earlier than those reported for movements of the limbs. The BP1 began approximately 3000ms prior to lip EMG onset and was followed by the BP2 at 2000ms premovement, which was consistent with the latencies of the BP recorded prior to speech and complex movements from prior studies (Deecke et al., 1986; Kristeva, 1984; Wohlert, 1983). However, a grand average of data from the 18 participants demonstrated no morphological distinctions between the BP1 and BP2. The grand average also revealed maximum amplitude variations within the interval of 2000ms prior to movement onset. In accordance with this finding the BP amplitude

was operationally defined, in the present study, as the average amplitude between 2000ms premovement and articulator movement onset. For the purpose of assessing the laterality and anteriority effects described in the hypotheses section, homologous electrode pairs were selected to represent individual cortical regions. Electrode pairs FC1-FC2 and FC3-FC4 were selected to represent the left and right lateral premotor cortices. The left and right dorsolateral frontal region was represented by electrodes F3 and F4. The primary motor cortical representations of the face in the left and right hemispheres were represented by electrodes C5 and C6. Finally, the SMA proper and the anterior medial cortical region, including Pre-SMA and the rostal portions of the cingulate cortex, were represented by CZ and FCz respectively. Averaged voltages of the BP from electrodes representing right hemisphere or posterior medial cortical regions were compared to BP voltages from their left homolog or in the case of the electrode representing the posterior medial cortex, the electrode to its immediate anterior. Mean amplitude values were obtained from ERP data recorded during each of the three tasks described below for statistical comparison.

Tasks

Participants were seated in an electrostatically shielded room approximately three feet from a 17 inch flat screen LCD monitor. For each of the three tasks, trials began with a visual cue. Participants were required to wait approximately 3 to 5 seconds following the cue and then make a vocal response. The participants were asked not to mentally count out this time interval, but instead to use their best guess as to when this interval had passed. In order to maximize the participant's timing accuracy several practice trials were performed in which the experimenter timed the participant's response latencies, and provided feedback as to the accuracy of the participant's timing. Practice was concluded once a participant accurately estimated the interval on five consecutive trials.

Participants were asked to keep their eyes open during the experiment and to visually fixate on a grey cross located in the center of the computer monitor. Participants were also instructed to relax their jaw, and to allow their mouth to remain slightly open when they were not actively responding to a cue. They were also requested to allow their tongue to return to the floor of their mouth after each utterance, in order to provide an accurate baseline position for the measurement of

tongue movement during spoken responses. In preliminary studies, it was observed that small fluctuations in lip recorded EMG sometimes preceded utterances by up to 1500ms, making it difficult to accurately determine the onset of speech related muscle movement. When participants were asked to make more abrupt responses, this problem was somewhat improved. This was further improved when participants were asked to monitor their own EMG prior to the experiment. The problems associated with "noisy" EMG were explained to them. They were asked to practice speaking sharp and crisply, in order to produce clear EMG deflections at the onset of speech.

Approximately 90 trials were recorded for each of the three verbal tasks. The present study was originally proposed with 4 tasks. However, one task, in which participants were required to name line drawings of common objects, was dropped from the study. This task produced BP distributions which were topographically very similar to 2 of the remaining tasks (See Figure 3) and increased the duration of the study by approximately 20 minutes per participant. Task order was counterbalanced between participants, with the exception of the Verbal Fluency task, which by necessity always preceded Word Reading.

Verbal Fluency Task (VF) Eleven category names (Mammals, Fish, Birds, Vegetables, Fruit, Trees, Beverages, U.S. States, Furniture, Musical Instruments, and Tools) were presented to participants in random order. Interstimulus intervals (ISI) varied from 8 to 10 seconds between trials. Participants were instructed to wait approximately 3 to 5 seconds after the presentation of a category name and then to name a member from the category. For example, after the cue "Mammal" was presented, an appropriate response would have been "Bear" or "Rabbit". Participants were encouraged to generate unique category members for each trial and not to name the same member more than once. A research assistant monitored and transcribed the participant's verbal responses.

Word Reading Task (WR) Participants were cued with textually presented, randomized items taken from their Verbal Fluency task responses. Items were presented at the same ISI as in the Verbal Fluency task. Participants were instructed to wait 3 to 5 seconds and then to repeat aloud each presented word.

Simple Speech Task (SS) The single word "pool" was presented repeatedly at the same variable ISI mentioned above. Participants were instructed to wait approximately 3 to 5 seconds and then to repeat the word "pool" aloud.

Data Analysis

The hypothesized effects of task on the lateral and medial BP distribution were assessed through comparisons of mean amplitudes between paired electrodes.

Two factor repeated measures analyses of variance (ANOVA) were performed for each of the hypothesized regional differences in BP topography. Thus, 4 separate ANOVAs were conducted to test for hypothesized hemispheric asymmetries over the frontal, superior frontocentral, mid frontocental, and central regions and a fifth to test medial differences in topographic distribution. Factors included were Task: 3 levels (Verbal Fluency, Simple Speech, and Word Repetition) X Electrode: 2 levels (Left and Right or in the case of medial differences, Anterior and Posterior). Task and electrode were treated as repeated variables. Due to potential covariation between experimental conditions, introduced by the repeated measures design, the Huynh and Feldt Epsilon correction was applied to each calculated F-statistic. All tests were held to a family-wise α of .05. Planned comparisons were performed only when the F-test associated with a specific hypothesis produced an interaction significant at $p \leq .05$. Hypotheses specific mean comparisons were performed using paired t-tests, with Bonferroni

corrections in order to maintain the specified experiment-wise type I error rate.

Planned Comparisons

Midline t-tests It was hypothesized that the VF and WR conditions would produce a shift in the maximum midline BP amplitude to the anterior relative to the SS condition. In addition, it was anticipated that VF would produce greater midline mean amplitudes (anterior and posterior) when compared to WR. Following significant interaction F-test, 7 t-tests were planned to test this hypothesis and are described in table 1.

Lateral t-tests Left lateralized BP amplitude asymmetries were hypothesized for the VF condition over the frontal, frontocentral, and central scalp regions. In contrast, more symmetrical lateral distributions were anticipated for WR and SS. Additionally, left frontal amplitude differences were anticipated between conditions. VF was expected to produce the greatest mean BP amplitude over the left frontal electrode, followed by WR, and finally SS. No differences in right frontal amplitude were anticipated. After significant F-tests, 13 follow-up t-tests were planned in order to test the individual comparisons specified by this hypothesis. These tests are described in table 2.

Results

Although the Bereitschaftspotential was traditionally associated with motor planning and readiness prior to distal limb movement, it was proposed that articulatory complexity and cognitive/semantic involvement both contributed to variations in the topography of the BP preceding speech. Tasks were designed to dissociate the proposed effects of these two aspects of language production on the topographic distribution of the BP. Specifically, it was hypothesized that increased articulatory complexity would produce a midline shift in maximum BP voltage to the anterior. Thus, the Verbal Fluency (VF) and Word Reading (WR) tasks, in which the articulatory structure of the utterances varied across trials, were anticipated to produce greater BP midline negativity at the frontocentral midline, while the Simple Speech (SS) task was expected to result in maximum BP amplitude over the vertex. In addition to the midline topographic shift associated with articulatory complexity it was also anticipated that semantic information processing would result in an increase in BP amplitude at the anterior midline recording site (FCZ). Thus, it was hypothesized that the VF task would yield higher BP amplitude than WR and SS at electrode FCZ. Secondly, cognitive/semantic involvement was also hypothesized

to produce lateralized asymmetries in the BP topography. It was therefore expected that the VF task, which required a semantically based search of the mental lexicon, would result in left lateralization of the BP waveform, while the WR and SS tasks, merely requiring articulation of textually presented words, would produce more symmetrical BP distribution. Furthermore, simple effects of condition were also expected over the left dorsolateral frontal region. It was hypothesized that VF, in comparison to the remaining two tasks, would produce the highest BP amplitude at electrode site F3, overlying this region.

Behavioral Findings

As mentioned previously, in each of the three tasks participants were instructed to wait approximately 4 seconds, following textual cues, before making a spoken response. For the SS task, the mean response latency was 3.32s and for WR and VF the means were 3.35s and 3.76s, respectively (see Figure 4). Participant's mean response latencies by task were analyzed using a one way repeated measure ANOVA. It was found that response latency did not significantly vary among tasks, $F(2,30)=2.58$, $p=.1114$, $\varepsilon=0.7346$.

Electrophysiological Findings

Separate 2 (electrode site) by 3 (task) repeated measures ANOVAs were performed in order to determine if task manipulations led to distinct topographic differences in the BP distribution. Task and electrode were treated as repeated variables. The Huynh-Feldt Epsilon correction was applied to all F-tests in order to compensate for possible positive bias introduced by the repeated measures design. Interactions of Task and Electrode site with F-values significant at .05 or lower were followed by planned t-tests, in order to test each of the hypothesized topographic effects on the BP distribution. In order to maintain family-wise type I error rate of .05, Bonferroni corrections were applied each set of pair-wise comparisons. The BP mean amplitude between 1000ms premovement and the onset of articulation served as the dependent measure for all analyses of electrophysiological data.

Electrode nomenclature conformed to the extended international 10/20 electrode placement system (Neuroscan Labs, 1998). Electrode pairs selected for statistical analysis were chosen based on their proximity to underlying cortical regions purported to play a role in the preparation and execution of speech. Electrodes CZ, located at the scalp vertex, and FCZ,

places approximately 3.5cm anterior to CZ were selected for statistical comparison in order to test for the hypothesized midline anterior shift in BP maximum amplitude with increased articulatory complexity. CZ and FCZ were chosen for their proximity to SMA and pre-SMA, respectively. Hypothesized left lateralizing effects on BP amplitude due to task related cognitive/semantic involvement were tested over the central, fronto-central, and frontal scalp regions. For the central scalp region electrode coordinates C5 and C6 were selected due to their proximity to the lips, tongue and jaw fields of the primary motor cortex. Pairs FC1-FC2 and FC3-FC4 were selected for comparison from the fronto-central scalp region. These coordinates were believed to overlie the lateral premotor cortex. Finally, electrodes F3 and F4, overlying the dorsolateral frontal region were selected for comparison. Visual inspection of pilot data revealed a robust, task-related left lateralization between these electrode coordinates.

Midline Anterior Shift in Maximum Amplitude

As hypothesized, the midline BP maximum amplitude was shifted to the anterior for tasks involving complex articulatory movements (see Figure 5). This was supported by a two way repeated measures ANOVA, which revealed a significant

interaction of Electrode Site and Task $F(2,68)=7.35$, $p= .0046$, $\varepsilon= 0.6955$. One tailed t-tests indicated that the mean BP amplitudes of the posterior midline electrode (CZ) and the electrode to its anterior (FCZ) were significantly different for the VF, $t(68)= 4.21$, $p=.0003$, and WR, $t(68)= 2.61$, $p=.0388$, conditions. In contrast, the SS task produced maximum midline amplitude at the posterior site, as was anticipated. However, amplitude differences between FCZ and CZ were not significant for the SS task, $t(68)= -1.078$, $p=.9972$ (see Table 3).

Main effects of task were found to be significant for both the anterior and posterior midline electrodes, $F(2,68)=30.15$, $p< .0001$, $\varepsilon= 0.6955$ (see Figure 6). Mean BP amplitudes from the anterior channel, compared using one tailed t-tests, were significantly different between the VF and WR conditions, $t(68)=4.31$, $p=.0003$, and also between the WR and SS conditions, $t(68)=3.74$, $p=.0014$. Main effects of condition at the posterior channel were significant only between VF and WR, $t(68)=2.71$, $p=.0294$ (see table 3).

Lateral Asymmetries in BP Topography

Support was also found for hypothesized task-specific hemispheric asymmetries in the BP topographic distribution (see Figure 7). A repeated measures ANOVA of the mean BP amplitude

recorded at frontal electrode sites F3 (left) and F4 (right) produced a significant interaction of Electrode Site and Task, $F(2,68)=4.27$, $p= .0198$, $\varepsilon= 0.9467$. Left and right mean amplitudes within each of the tasks were compared using Bonferroni corrected one tailed t-tests. As expected, VF, the more cognitively challenging of the conditions, produced a significant left lateralized frontal distribution, $t(68)=-4.34$, $p<.0003$. Frontal hemispheric asymmetries were not found for speech tasks which required more simplistic cognitive operations. Comparisons of BP mean amplitudes between the left and right frontal sites were not significant for WR, $t(68)= 1.45$, $p=.5257$ and SS, $t(68)=-0.33$, $p=1$. (see Table 4).

Additionally, main effects of condition were found for means derived from recordings at the left frontal channel, $F(2,68)=30.07$, $p <.0001$, $\varepsilon= 0.9467$ (see Figure 8). One tailed t-tests indicated that amplitude differences between VF and WR ($t(68)=4.26$, $p=.0003$) and WR and SS ($t(68)=3.23$, $p=.0067$) were statistically significant. Amplitude differences at the right frontal channel were not significant (see table 4).

Post Hoc Analyses

Although hemispheric asymmetries over the frontocentral and central scalp regions were anticipated for the VF task, no

significant interactions between task and hemisphere were found for any of these regions. However, main effects of task were revealed for both regions. A Task by Electrode Site repeated measures ANOVA revealed a significant main effect of Task for the combined fronto-central electrodes FC1 and FC2, $F(2,68)=26.55$, $p< .0001$, $\varepsilon= 1.0121$. Two tailed, Bonferroni adjusted t-tests indicated that the mean BP amplitudes recorded over the superior frontocentral region (i.e. at both FC1 and FC2) were significantly different between VF and WR, $t(68)=4.32, p=.0002$; VF and SS, $t(68)=7.24$, $p=.0001$; and WR and SS, $t(68)=2.91, p=.0144$ (see Table 5). Similarly, a 2-way repeated measure ANOVA resulted in a main effect of task for the combined electrodes of the mid frontocentral region (i.e. FC3 and FC4), $F(2,68)=20.08$, $p< .0001$, $\varepsilon= 1.0593$. Two tailed Bonferroni corrected t-tests indicated significant differences between VF and WR, $t(68)=-2.73, p=.0241$; VF and SS, $t(68)=-6.32, p<.0001$; and WR and SS, $t(68)= -3.59$, $p=.0019$. A two way repeated measures analysis of the BP means from the central electrode sites (e.g. C5 and C6)revealed a main effect of Task, $F(2,68)=8.08$, $p= .0001$, $\varepsilon= 0.9209$. Bonferroni corrected two tailed t-tests indicated significant differences between the means of VF and WR, $t(68)=-2.94, p=.0134$; and VF and SS, $t(68)=-$

3.84, p=.0008. Differences between WR and SS were not significantly different, t(68)=-0.90, p=1 (see Table 6).

Discussion

The primary purpose of this experiment was three fold. First, at the most basic level, the experiment was conducted in order to demonstrate that the BP could be reliably derived from EEG data, recorded prior to speech. In order to achieve this, it was necessary to first overcome certain methodological issues, which will be discussed further below. A second goal of the study was to determine if certain task related factors could modulated the topographic distribution of the BP. More specifically, it was anticipated that increases in the articulatory complexity of the utterances spoken by the participants would result in a midline anterior shift in the maximum BP amplitude. Finally, it was expected that the addition of a lexical/semantic search to the speech task would produce even greater midline negativity and left lateralized asymmetries in the BP topographic distribution. A hierarchical series of speech tasks were selected in order to first, demonstrate a speech related BP, and then dissociate the effects of articulatory complexity from the proposed effects of lexical/semantic processes on the BP topography. However, as mentioned above, several researchers have questioned the

feasibility of recording the BP prior to speech. Brooker and Donald (1980) and Morrell and Huntington (1972) both concluded that the speech BP could not be recorded independent of articulation related EMG due to the close temporal and spatial proximity of the two events. It was therefore first necessary to address this methodological concern and devise a means of recording the speech BP independent of articulatory movements.

Early, preparatory movements of the articulators have been identified as the most likely source of EMG contamination to the speech BP. This was most apparent in the earliest of speech movement studies, where the onset of the acoustic signal served as a marker for BP averaging (Grabow & Elliot, 1974; McAdam & Whitaker, 1971; Morrell & Huntington, 1972; Szirtes & Vaughan, 1977). More recent studies attempted to avoid EMG contamination by time-locking the average to the onset of lip movement (Deecke et al., 1986; Wohlert, 1993). However, lip movement does not always precede the movements of the remaining articulators. Rather, the order of articulator movements varies considerably between words, due in part to phonological pattern differences. For example, the word “Piranha” typically begins with bilabial movement, while the word “Dog” begins with movement of the tongue (see Figures 9 and 10). To contend with this, many of the

studies to date have constrained the utterances spoken by their participants to either a single word or a limited set of words, which were assumed to begin with movement of the lips. However, this strategy could be applied to relatively few tasks and limited the types of linguistic operations readily studied using a BP paradigm. Furthermore, recent evidence from x-ray microbeam recordings of articulatory movements of the tongue and lips suggests kinematic variability not only between speakers, but also within the same speaker during repetitions of a single utterance (Westbury, Severson, and Lindstrom, 2000). Thus, even when utterances are tightly constrained to those beginning with so called bilabial phonemes, it must still be assumed that motions of the lips precede those of the tongue, unless both articulators are monitored.

In order to overcome these methodological restrictions a series of pilot studies were conducted in order to devise effective, reliable means of identifying the onset of speech movement from multiple articulatory muscles. Artifact free BP averages could then be derived by time locking individual trials to the earliest source of articulator movement on a word by word basis.

A review of the relevant literature implicated movements of the tongue and lips as having the greatest potential to produce EMG contamination during articulation. In addition, the glottis also appeared to be a likely source. While standard bipolar electrode pairs could be utilized for recording EMG from the lips, the motions of the tongue and glottis could not be accurately monitored through EMG surface recording. Two methods, novel to ERP research, were adopted in order to monitor tongue and glottal movements. First, Doppler imaging was examined as a means of determining the onset of tongue movement. As noted previously, direct measurements from the tongue have been problematic, due to its enclosure in the oral cavity and throat. Doppler has been a popular means of imaging the tongue due to its noninvasive nature (Stone, 1999) and the temporal resolution it provides makes Doppler highly suitable as an index of the onset of tongue movement during articulation. Second, early pilot work utilized the electroglottogram as a means of determining glottal adduction during speech. However, during pilot studies there were no instances observed of glottal movement preceding those of either the lips or tongue during the articulation of single words.

The principal advantage of utilizing motion onset information from both the lips and tongue was that speech onset could be determined for the phonological pattern of any single word utterance. This was beneficial in several ways. First, participants could select their verbal responses on a purely semantic basis, irrespective of any phonological constraints. It was therefore possible to study the effects of a semantically based search of the mental lexicon. Rarely are there incidence in naturally occurring language operations were a speaker intentionally limits her word selection to those with a specific phonological structure (with the exceptions of crossword puzzles and poetic compositions). More typically, word retrieval is meaning based, thus tasks requiring semantics based lexical search, such as the semantically cued verbal fluency task used in the present study, are more ecologically valid, and thus, generalizeable to natural spoken language.

Midline Effects of Articulatory Complexity and Semantic Processing

Confirmatory evidence was found in support of the two primary hypotheses. First, it was hypothesized that increased

articulatory complexity would result in an anterior midline shift in the maximum BP voltage. Thus, it was anticipated that the Verbal Fluency (VF) and Word Reading (WR) tasks, in which spoken responses and consequentially the articulatory patterns of utterances varied across trials, would produce greater BP midline negativity at the frontocentral midline, while the Simple Speech (SS) task was expected to result in BP maximum over the vertex. A significant interaction between task and electrode site supported this hypothesis. Mean BP amplitudes in the VF and WR tasks were significantly greater at the anterior (FCZ) when compared to the posterior midline site (CZ). In contrast, the SS condition produced greater BP negativity at CZ in comparison to FCZ, though the difference was non-significant (see Figure 5). Moreover, evidence was found in support of the second hypothesis. It was anticipated that the addition of a semantics based search to the speech task would result in increased BP amplitude at the midline electrode sites. This was confirmed. The VF task, which required the participants to generate exemplars from several categories, produced significantly greater BP amplitude at both FCZ and CZ than the WR task, in which the responses were read (see Figure 6). These findings suggest that the midline cortical regions support two

roles in the formulation of spoken language. First, it appears that the region subserves the production of relatively complex articulatory patterns, which is in agreement with findings from PET studies of both limb and speech movements. For example, Picard and Strick (1996) concluded from their review of PET movement studies that task complexity played a significant role in the pattern of medial motor area activation. Movements requiring basic temporal or spatial organization, such as a button press, typically only elicit medial increases in rCBF within the region of SMA proper. Tasks requiring more complex sequences of movement, movements which were unfamiliar to the participants or movements based on choice resulted in additional increases in the pre-SMA and rostral portions of the cingulate motor area (CMA). A similar shift in topography of the BP has also been demonstrated for complex movements of the distal limbs (Niemann, Winker, Gerling, Landwehrmeyer, & Jung, 1991; Schreiber, Lang, Lang, Kornhuber, Heise, Keidel, Deecke & Kornhuber, 1983), and more recently, using both source localization techniques (Cui, Huter, Egkher, Lang, Lindinger, & Deecke 2000) and event related fMRI (Deecke, 2000), researchers have confirmed that this midline topographic shift in maximum BP amplitude is related to the recruitment of pre-SMA and CMA for

tasks requiring more complex finger movements. However, the present study has been the first to demonstrate a similar anterior progression for complex speech. Secondly, the present findings also suggest that the anterior midline region plays a role in the semantic processes underlying categorical word retrieval. As mentioned above, the VF task produced significantly greater BP amplitude at FCZ (anterior midline) than the WR or SS tasks. Studies using PET have demonstrated increased pre-SMA activation for speech tasks requiring the retrieval of semantic information, when compared to word reading (Wise, Chollet, Hadar, Friston, Hoffner, & Frackowiak, 1991; Petersen et al., 1988). Thus it is reasonable to infer that the anterior shift in BP amplitude demonstrated in the present study during semantic verbal fluency was due to pre-SMA involvement. Unlike the SMA proper, the pre-SMA has numerous reciprocal connections with the prefrontal cortex. It therefore seems plausible that the pre-SMA subserves functional roles in both articulation and higher order linguistic operations.

Speech has been described paradoxically in the literature as both highly overlearned (Levelt, 2001) and as one of the most motorically complex of human behaviors (Ackermann & Riecker, 2005). Levelt reasoned that by adulthood an individual will have

repeated each of the most common syllables in his or her native language an estimated 100,000 times. Thus, articulatory gestures could be placed among the most exercised of all motor patterns produced. However, languages such as English and German have been estimated to contain as many as 500 commonly used syllables and approximately 12,000 syllables overall (Dogil, 2002). Furthermore, normal speech requires quick and accurate execution of motions from over 100 articulatory muscles, many of which can be independently controlled. Gestures produced by these muscles typically overlap and many speech sounds require the interleaving of gestures, a phenomenon referred to as co-articulation. Precise coordination of these gestures with respiratory processes must also be achieved, thus placing even greater demands on the motor system. Thus, while qualifying as overlearned, spoken language is at the same time one of the most complex of human behaviors.

Lateral Effects of Articulatory Complexity and Semantic Processing

As with the midline BP topography, unique effects of articulatory complexity and semantic involvement were found for the fronto-lateral scalp region. Cognitive/semantic involvement

was hypothesized to produce lateralized asymmetries in the BP topography. It was therefore expected that the VF task, requiring a semantic based search of the mental lexicon, would result in left lateralization of the BP waveform, while the WR and SS tasks, merely requiring articulation of textually presented words, would produce a more symmetrical BP distribution. An interaction between condition and frontolateral electrode site provided confirmatory support for this hypothesis. Mean BP amplitude differences between the left (F3) and right (F4) frontolateral electrode sites were significant only for the VF condition (see Figure 7). Hemispheric asymmetries over the fronto-central and central scalp regions were not significant. Furthermore, main effects of condition were found at the left dorsolateral frontal site (F3) between each of the three tasks. Left frontolateral mean BP amplitude was greatest prior to the VF task, followed by WR and then SS (see Figure 8). Amplitude differences were not significant between conditions at the right frontocentral site (F4).

Based on these findings, it does appear that under certain conditions the speech related BP is markedly left lateralized over the mid-frontal region. Several previous studies found no evidence of hemispheric lateralization (Wohlert, 1993; Brooker &

Donald, 1980; Grabow & Elliot, 1974; Morrell & Huntington, 1972). These conflicting findings can be partially explained by differences in locations of the recording sites selected. With the exception of the study by Morrell & Huntington (1972) in which the recording sites were not disclosed, none of these speech BP studies included electrode sites to the anterior of the vertex. Furthermore, EMG contamination, resulting from movements of the tongue and other articulators, could possibly have masked any evidence of BP laterality in these previous studies. However, because left frontal BP laterality was only found in the Verbal Fluency condition of the present study a more likely explanation is that semantic processing results in the observed asymmetrical shift in the BP distribution.

Left laterality of language processes is not unexpected and ample evidence from imaging and electrophysiological studies lends support to this view. It is curious however that the topographic distribution of the BP, which is most commonly associated with readiness or preparation for volitional movements, would vary between linguistic tasks differing purely in terms of lexical operations. A growing body of literature suggesting a functional relationship between motor and language cortical networks may shed light on this unexpected finding.

Converging evidence from anthropological record and multiple other disciplines suggests that the cortical system subserving language gradually developed from a pre-existing gestural system of communication (Corballis 2003; Kimura, 1993; Liberman & Whalen 2000; Lieberman, 1975, 1984, 1985). A link between the language and motor systems has also been demonstrated by several studies which found changes in hemodynamic activation and electrophysiological amplitudes within the motor and premotor cortices for spoken and written linguistic stimuli (Pulvermüller, Hummel, & Härle 2001; de Lafuente & Romo 2004). Using transcranial magnetic stimulation (TMS) the reciprocity of the language and motor systems was recently demonstrated by Pulvermüller, Hauk, Nikulin, and Iimoniemi (2005). Participants performed a lexical decision task, while TMS was applied to specific cortical regions. When stimulation was applied to the arm representation in the left hemisphere there was a marked decrease in response times to words related to arm actions, such as swing or throw, on a lexical decision task. Similarly, stimulation of the leg region was associated with faster responses to words related to actions of the leg. Stimulation of the right homologous areas did not lead to facilitated response latencies. These findings clearly demonstrate an active role of

the cortical motor system in the processing of lexical information. The results of the present experiment also demonstrate an association between the language and motor systems and further extend the relationship to mesial structures believed to play a role in the planning, formulation, and execution of motor behaviors.

Limitations of the Present Study

There were several notable limitations of the present study. First, while Doppler affords both the high temporal and spatial resolutions, suitable for determining the onset of movements of the blade and pharyngeal surfaces of the tongue, the tongue tip is generally unobservable using this technique. The occlusion of the tongue tip is due to a small pocket of air below its surface. Thus, if the onset of movement at the tip of the tongue were to precede movements from the remaining surfaces of the tongue and the lips, EMG contamination could have been introduced into the data set. It is uncertain though whether the tongue tip can move without also producing some movement at the blade. Smith and Kier (1989) described the movements of the tongue as similar to those of a hydrostatic animal (i.e. squid), both rely on muscle for not only movement, but structural support. Considering that the volume of the tongue remains at all times invariant, a

dimensional change at one surface point, the tip for example, must produce a compensatory change in the dimensions of at least one other surface. Thus, while no evidence could be found to refute the possibility of tongue tip movements occurring independent of movements of the blade, given the physical structure and composition of the tongue it does not appear to be physically possible for such movements to occur.

A second and more serious limitation of the present study is common to all electrophysiological research, in which activity, presumed to originate in the brain, is recorded from electrodes on the surface of the scalp. The problem is that scalp recorded electrical potentials provide only limited inference as to their sources within the brain (see Figure 11). Two dimensional topographies from a limited number of recording sites invariably have multiple solutions. This is commonly referred to as the inverse problem (Scherg, Beucker, Weckesser, Bornfleth, Berg, & Hoechstetter, 2000). Multiple established source localizing methods do however exist and can dramatically increase the certainty of our inferences. Based on certain assumptions regarding the anatomy and physiology of the brain, source localization methods are used to minimize the probable sets of cortical regions responsible for a pattern of activity

measured at the scalp. As mentioned earlier, the BP potential is believed to originate in the medial premotor and primary motor regions. Support for this view has come from both epicortical electrophysiological recordings (Kunieda, Ikeda, Ohara, Matsumoto, Taki, Hashimoto, Baba, Ioue, Mihara, Yagi & Shibasaki, 2004) and functional imaging studies, which have reported activation patterns similar in distribution to the BP in these same regions (Cunnington, Windischberger, Deecke, & Moser, 2003). In the present study, BP asymmetries were found over the midfrontal region rather than the central region, where they are typically reported for contralateral distal limb movements. Thus, it would be of further interest to apply source localizing techniques to clarify the probable generator(s) of this laterality. As a first step, a current source density (CSD) analysis was applied to the BP data from the present study. This technique, when applied to scalp recorded electrical potentials produced topographic maps, similar to the more common interpolated ERP maps. However, CSD maps were more sensitive to proximate current sources than to distant volume conducted sources. Thus, electrical activity represented in CSD topographic maps were more likely to have originated from the cortical sources within their immediate vicinity. In the present

study, CSD maps demonstrated a clear midline anterior shift in the BP distribution for the VF and WR tasks when compared to SS. Moreover, a distinct left dorsolateral frontal source was clearly present for VF and WR. In contrast, simple speech showed no evidence of a lateralized frontal BP source (see Figure 12).

General Conclusions

In conclusion, 3 goals were achieved in the present study. First, unresolved methodological issues had led to a relative abandonment of speech related BP research. In short, several researchers suspected that it was not possible to accurately describe the speech BP independent of articulatory muscle artifacts. In the present study this issue was resolved. Novel means of monitoring articulatory movements were developed and BP averaging was time locked to the onset of the first of these articulatory movements on a word by word basis. Thus, it was demonstrated that the BP could be recorded, free of contamination from muscle movements, permitting accurate topographic mapping and description of the potentials characteristics. Second, topographic differences in the BP distribution were demonstrated between complex and simple articulatory patterns. These differences were most prominent between the frontal and central midline recording sites, but

also present over the left dorsolateral frontal region. Finally, it was shown that semantic lexical processes produce even further contributions to the topographic distribution of the speech BP. Although most prominent over the left dorsolateral frontal region, differences in the speech BP topography were also apparent over the anterior midline, roughly approximating the area of the pre-SMA.

Considering these findings, the BP should be considered a reliable tool for studying not only the motor aspects, but also the cognitive/linguistic processes which subserve the formulation of speech.

Table 1

Midline Hypotheses and Planned Comparisons

Hypothesis	Test
Midline BP amplitude will be greatest at the anterior, relative to the posterior channel for VF.	VF(FCZ > CZ)
Midline BP amplitude will be greatest at the anterior, relative to the posterior channel for WR.	WR(FCZ > CZ)
Midline BP amplitudes at the anterior and posterior channels will be equivalent for SS.	SS(FCZ = CZ)
Anterior midline BP amplitude will be greater for VF when compared to WR.	FCZ(VF > WR)
Anterior midline BP amplitude will be greater for WR when compared to SS	FCZ(WR > SS)
Posterior midline BP amplitude will be greater for VF when compared to WR.	CZ(VF > WR)
Posterior midline BP amplitude will be greater for WR when compared to SS	CZ(WR > SS)

Table 2

Frontal, Frontocentral, and Central Hypotheses and Planned Comparisons

Hypothesis	Test
VF will produce a left lateralized BP over the frontal region.	VF(F3 > F4)
No frontal BP amplitude asymmetries will occur for WR.	WR(F3 = F4)
No frontal BP amplitude asymmetries will occur for SS.	SS(F3 = F4)
Left frontal BP amplitude will be greater for VF when compared to WR	F3(VF > WR)
Left frontal BP amplitude will be greater for WR when compared to SS	F3(WR > SS)
Right frontal BP amplitude will be equivalent for VF when compared to WR	F4(VF = WR)
Right frontal BP amplitude will be equivalent for WR when compared to SS	F4(WR = SS)
Frontocentral BP amplitude will show a left lateralized asymmetry for VF	VF(FC3 > FC4)
No frontocentral BP amplitude asymmetries will occur for WR.	WR(FC3 = FC4)
No frontocentral BP amplitude asymmetries will occur for SS.	SS(FC3 = FC4)
Central BP amplitude will show a left lateralized asymmetry for VF	VF(C5 > C6)
Central BP amplitude asymmetries will occur for WR.	WR(C5 = C6)
Central BP amplitude asymmetries will occur for SS.	SS(C5 = C6)

Table 3

Midline Anterior and Posterior BP Mean Amplitudes by Condition

	Midline Electrode Site	
Condition	Anterior (FCZ)	Posterior (CZ)
Verbal Fluency	$-11.5349_{a,1}$	$-7.61528_{b,1}$
Word Reading	$-7.5204_{a,2}$	$-5.08678_{b,2}$
Simple Speech	$-4.03186_{a,3}$	$-5.03614_{a,2}$

Note. Means within the same row with differing alphabetic subscripts and means within the same column with differing numeric subscripts were significantly different at $p < .02$ when compared using one-tailed Bonferroni corrected t-tests.

Table 4

Frontal Hemispheric Asymmetries in BP Mean Amplitudes by Condition

	Frontal Electrode Site	
Condition	Left (F3)	Right (F4)
Verbal Fluency	$-11.591_{a,1}$	$-5.959_{b,1}$
Word Reading	$-6.072_{a,2}$	$-4.185_{a,2}$
Simple Speech	$-1.882_{a,3}$	$-1.445_{a,2}$

Note. Means within the same row with differing alphabetic subscripts and means within the same column with differing numeric subscripts were significantly different at $p < .02$, when compared using one-tailed Bonferroni corrected t-tests.

Table 5

Fronto-central BP Mean Amplitudes by Condition

Condition	Fronto-central Electrode Sites	
	FC1-FC2	FC3-FC4
Verbal Fluency	-8.188_{a}	-7.222_{a}
Word Reading	-4.942_{b}	-5.124_{b}
Simple Speech	-2.753_{c}	-2.369_{c}

Note. Means within the same column with differing subscripts were significantly different at $p < .02$ by two-tailed Bonferroni corrected t-tests.

Table 6

Central BP Mean Amplitudes by Condition

Condition	(C5-C6) Central Electrodes
Verbal Fluency	-4.726_a
Word Reading	-1.382_b
Simple Speech	-0.357_b

Note. Means with differing subscripts were significantly different at $p < .02$ by two-tailed Bonferroni corrected t-tests.

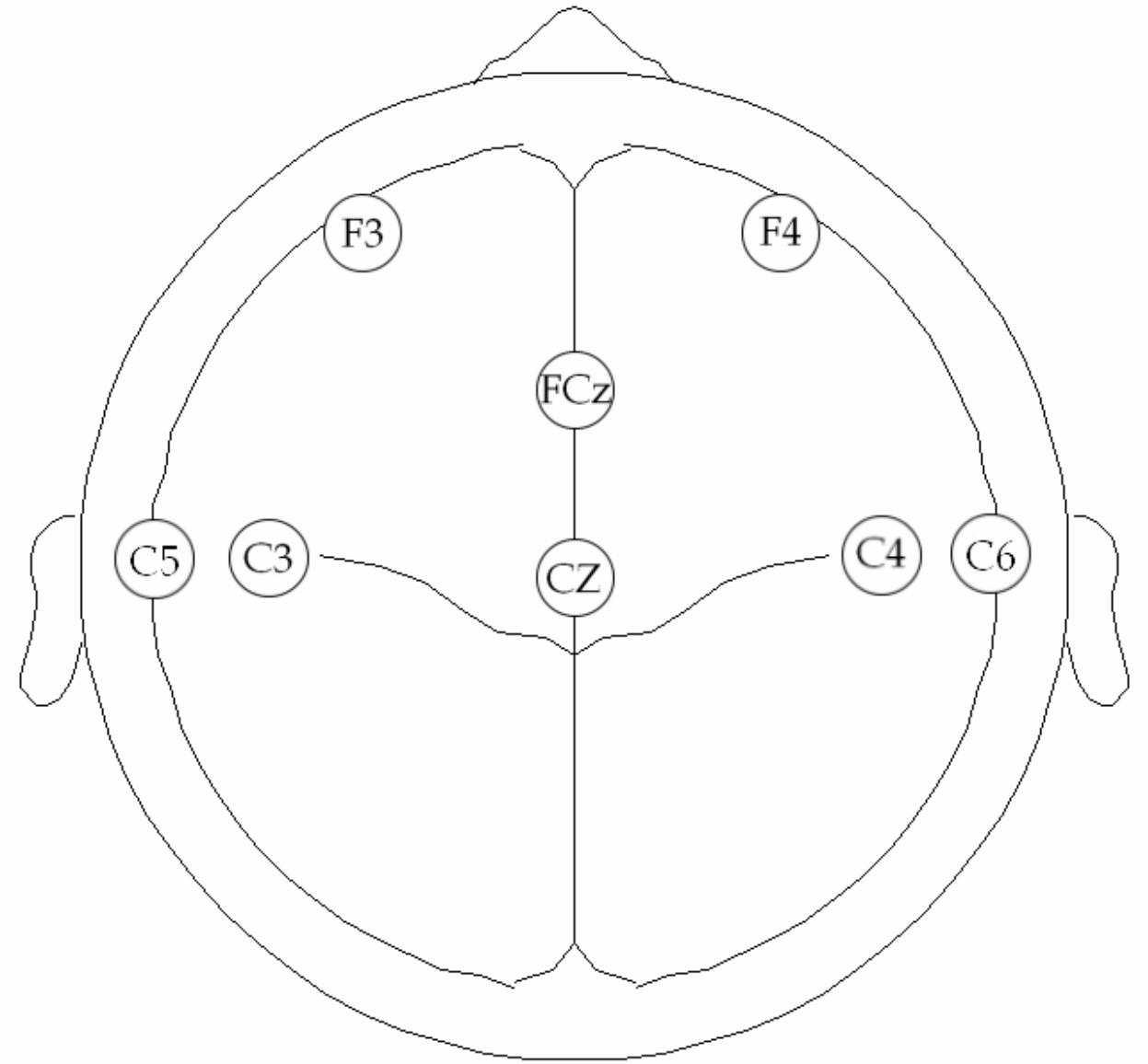

Figure 1. Approximate locations of dorsolateral frontal electrodes (F3 and F4), central electrodes (C3, C4, C5, and C6) and medial electrodes (FCz and CZ).

Simple Speech

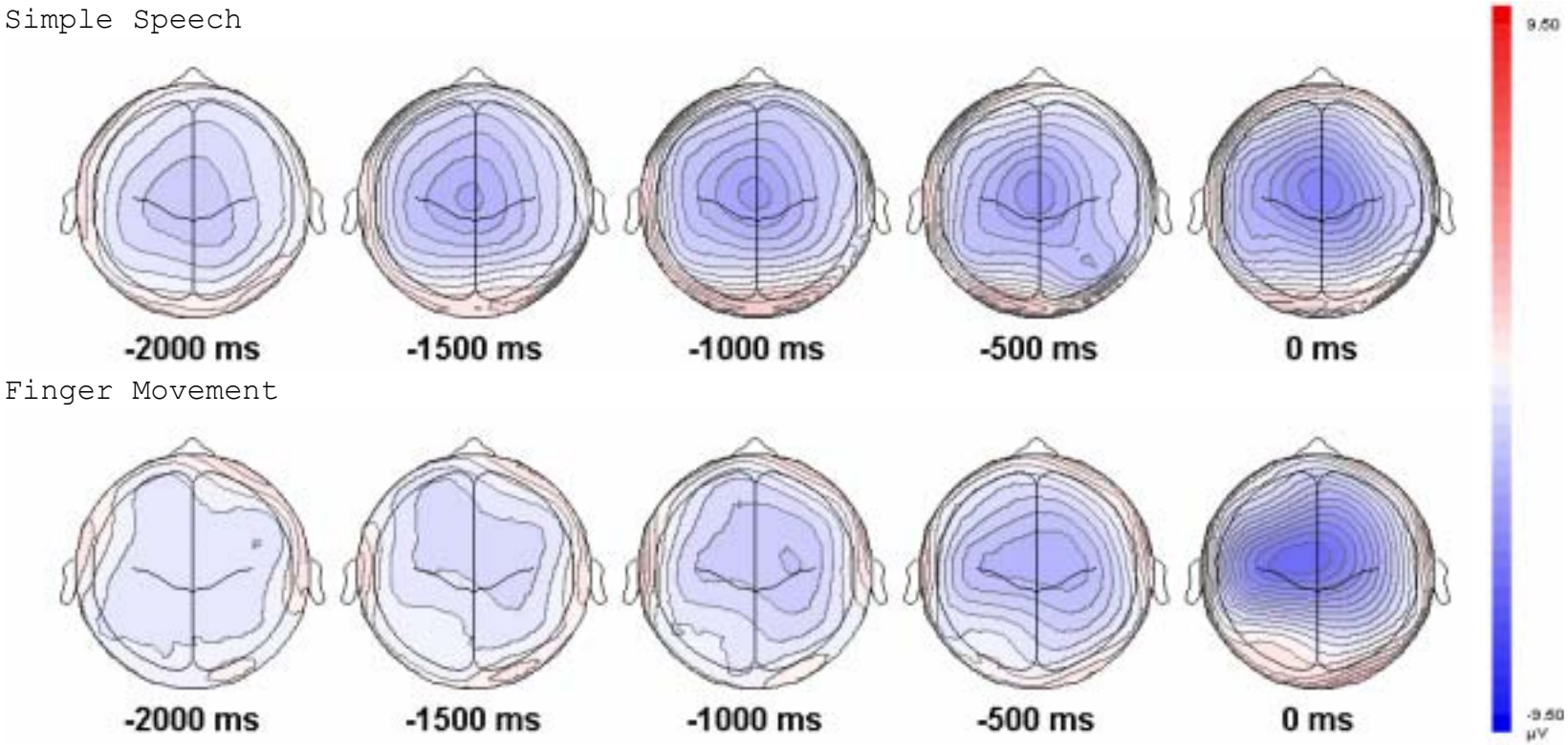

Figure 2. Comparison of the BP from the simple speech task to BP derived from movements of the right index finger.

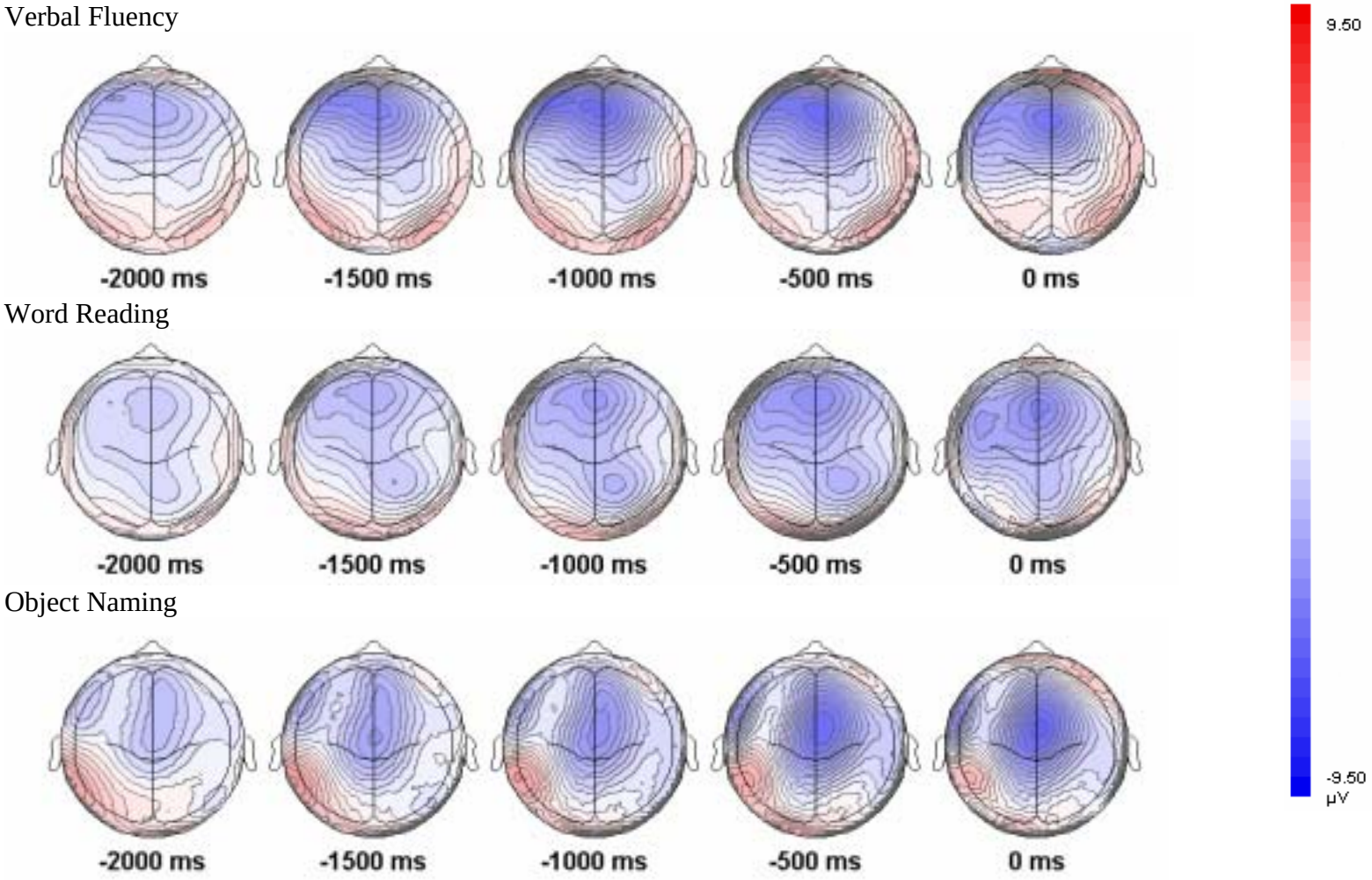

Figure 3. Comparison of the BP from the verbal fluency, word reading tasks and an object naming task.

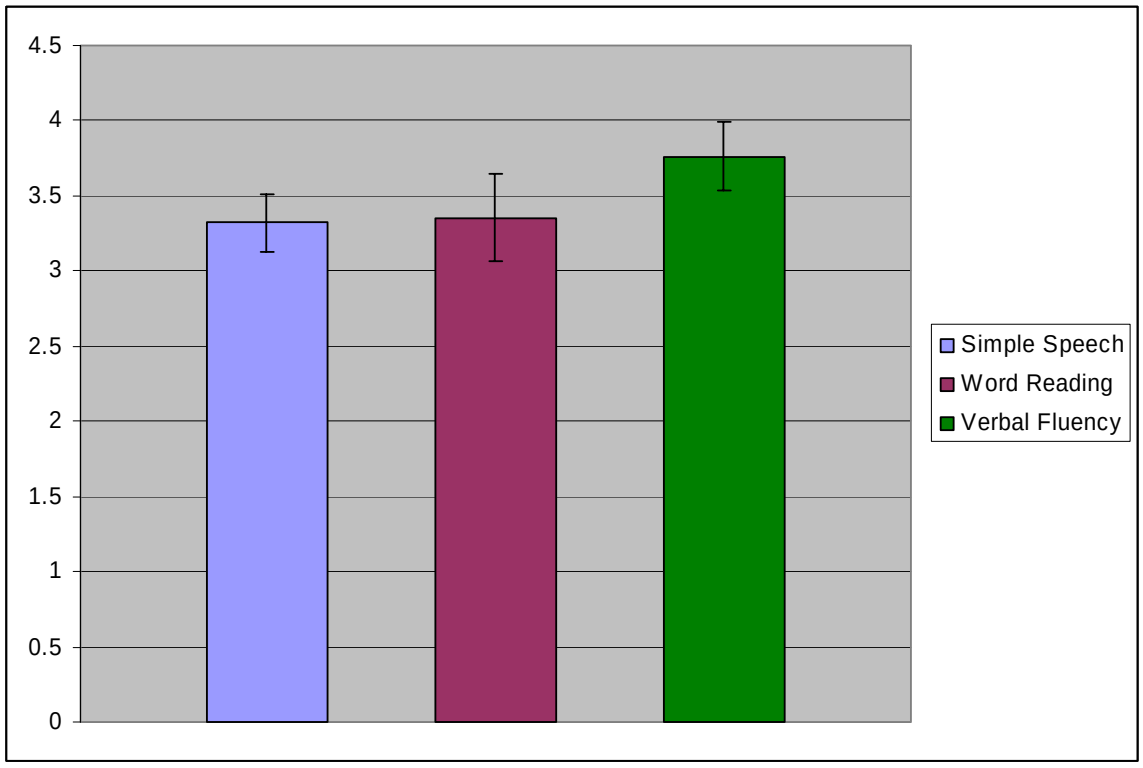

Figure 4. Latencies of articulator movement following visual cues. No significant latency differences were found between conditions.

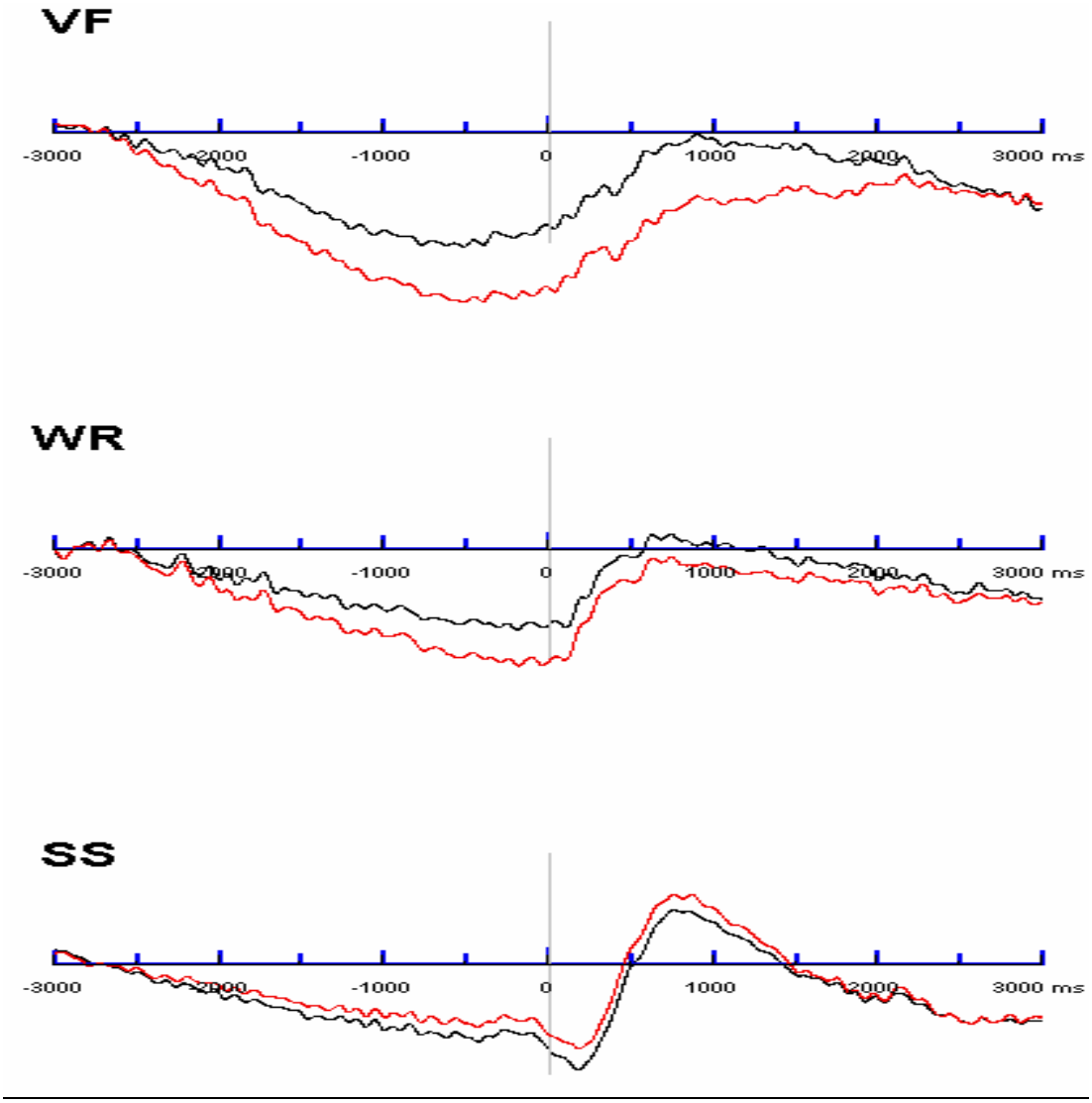

Figure 5. Comparison of averaged BP waveforms from anterior (red) and posterior (black) midline electrodes, in the verbal fluency, word reading, and simple speech conditions.

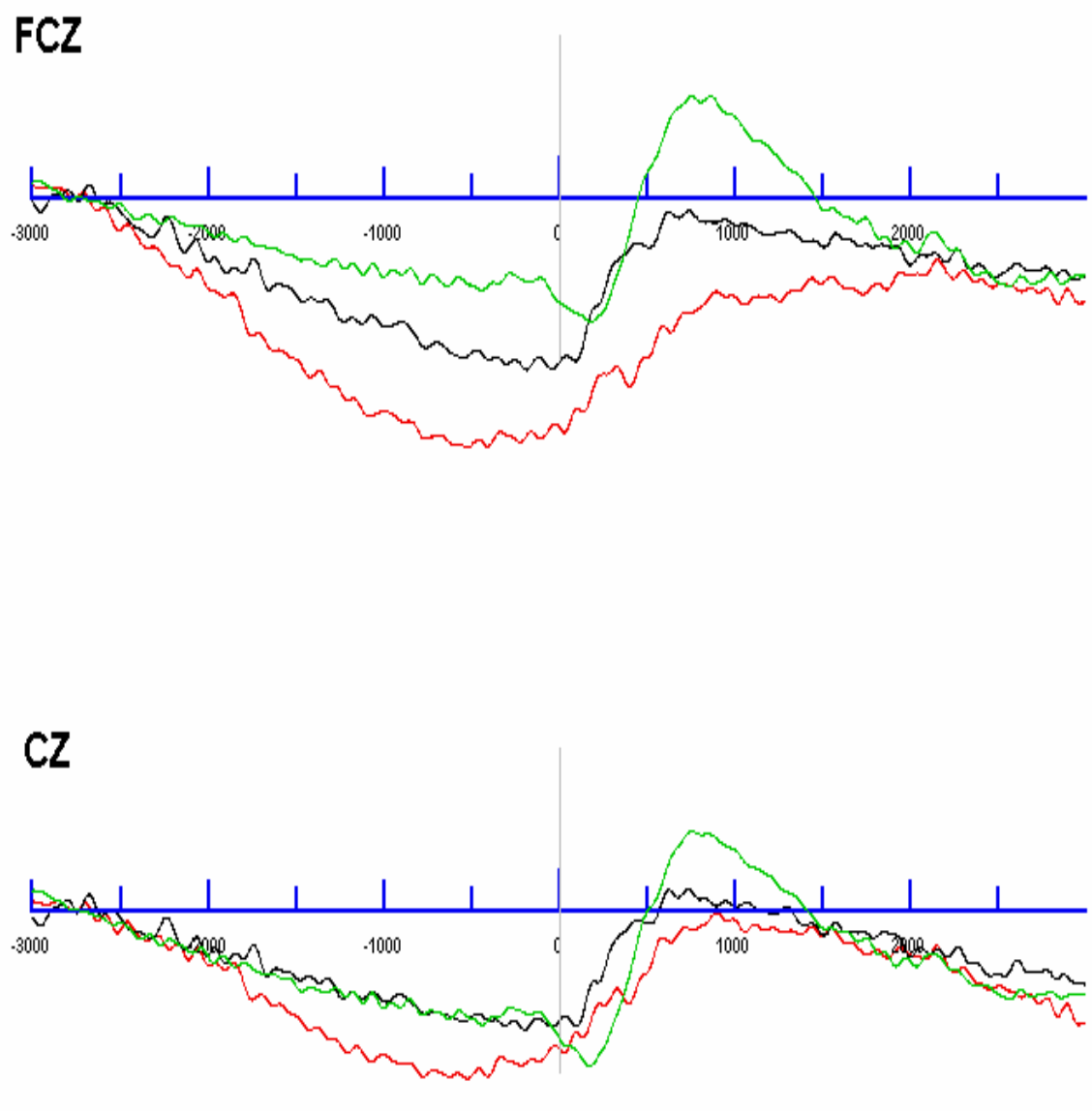

Figure 6. Comparison of averaged BP waveforms from verbal fluency (red), word reading (black), and simple speech (green) conditions, at anterior (FCZ) and posterior (CZ) midline electrodes.

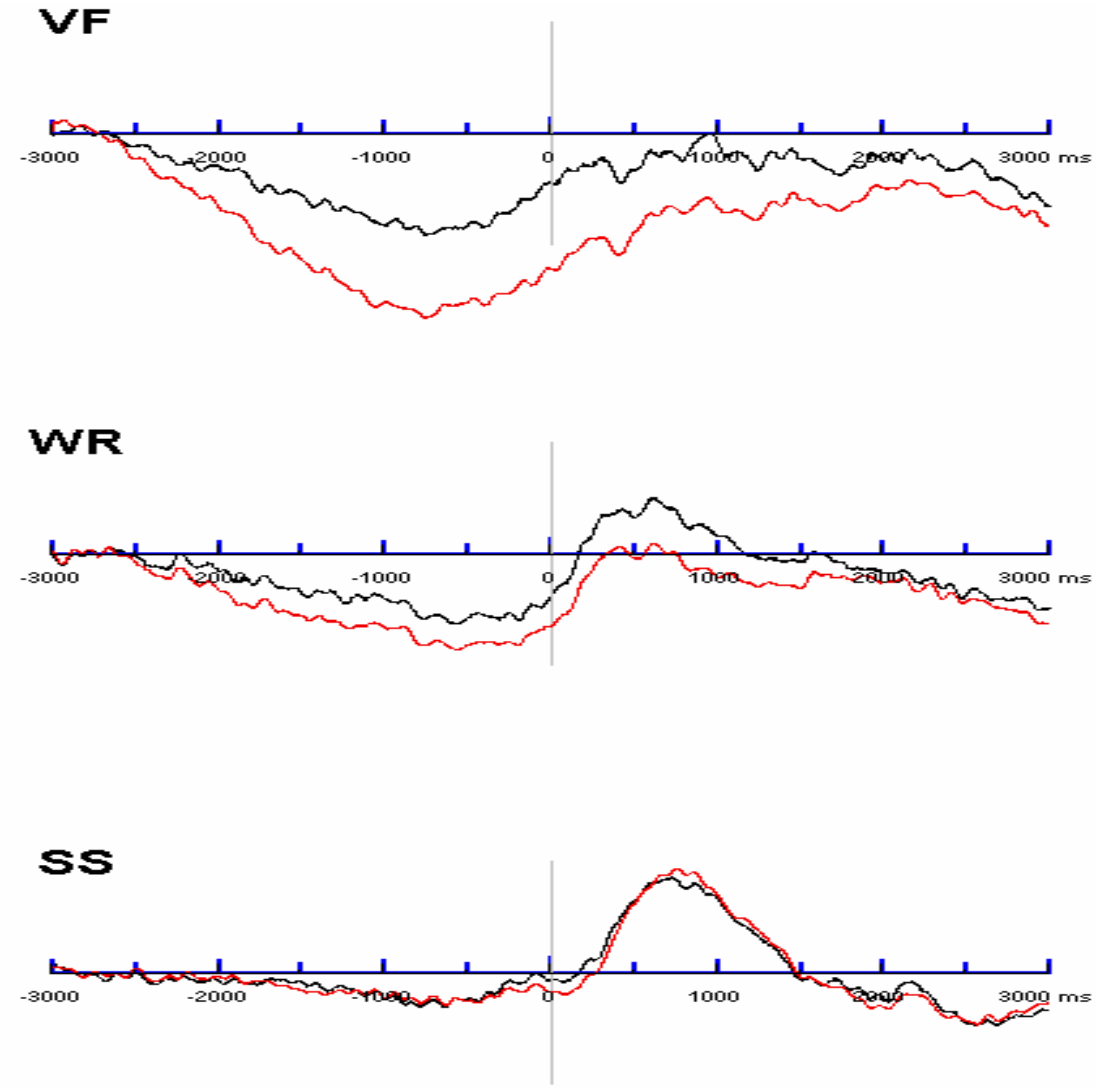

Figure 7. Comparison of averaged BP waveforms from left (red) and right (black) frontal electrodes, in the verbal fluency, word reading, and simple speech conditions.

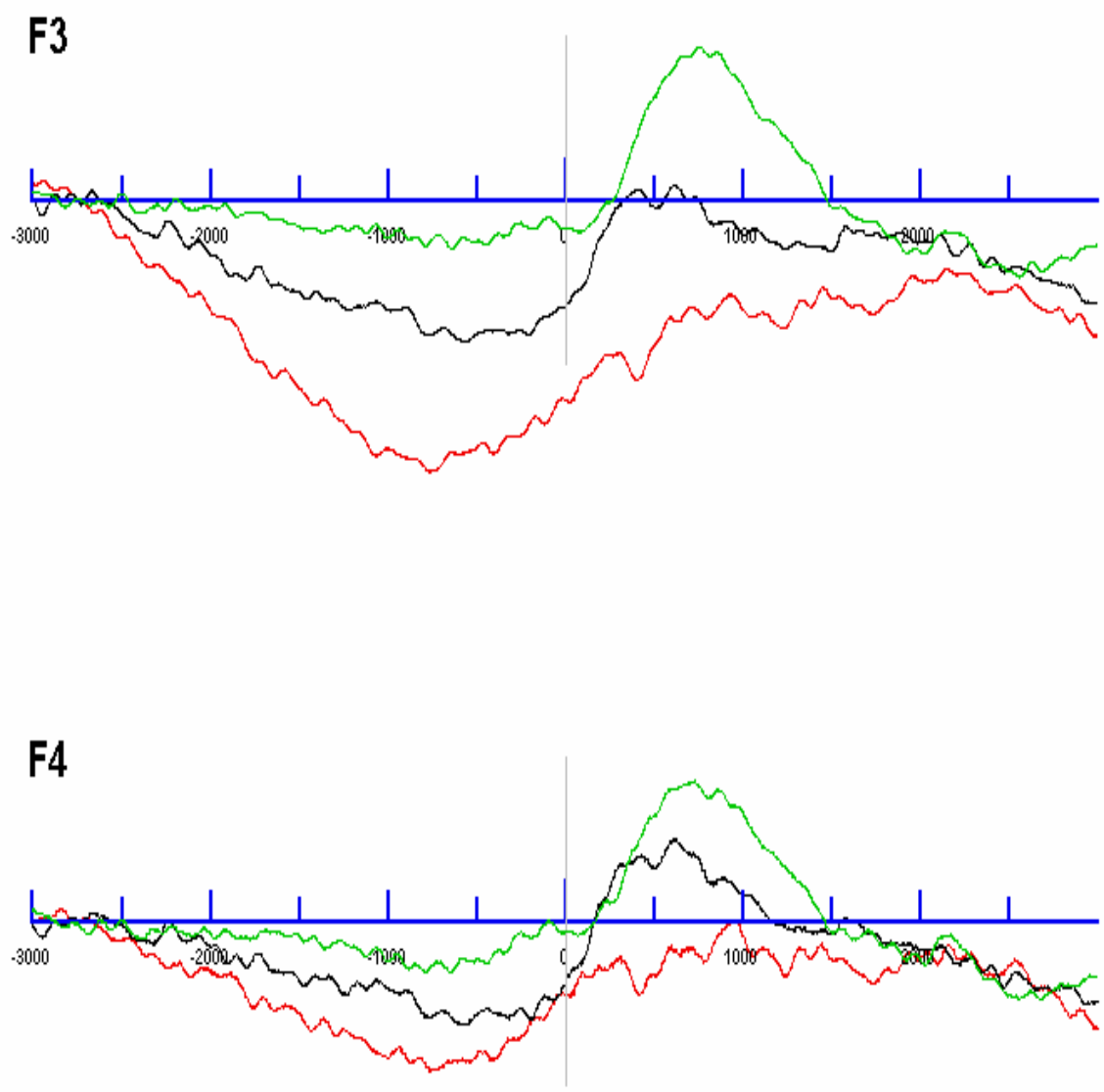

Figure 8. Comparison of averaged BP waveforms from verbal fluency (red), word reading (black), and simple speech (green) conditions, at left (F3) and right (F4) frontal electrode.

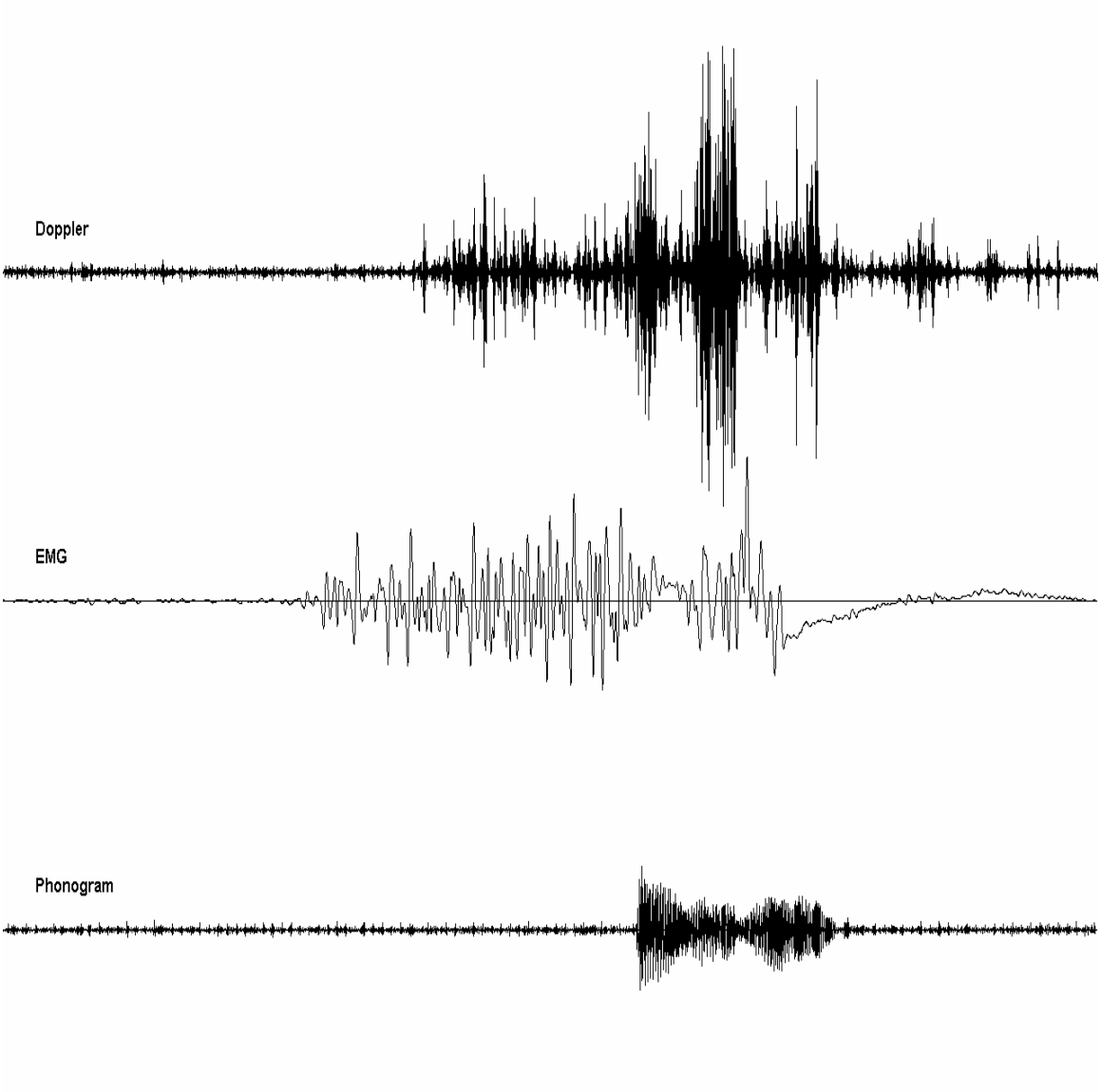

Figure 9. Synchronous recordings of articulation related movement from the tongue (top) and upper lip (middle), and the phonogram for a single spoken utterance of the word “Piranha”. Lip EMG begins 220ms prior to the onset of tongue movement and 600ms prior to the phonogram.

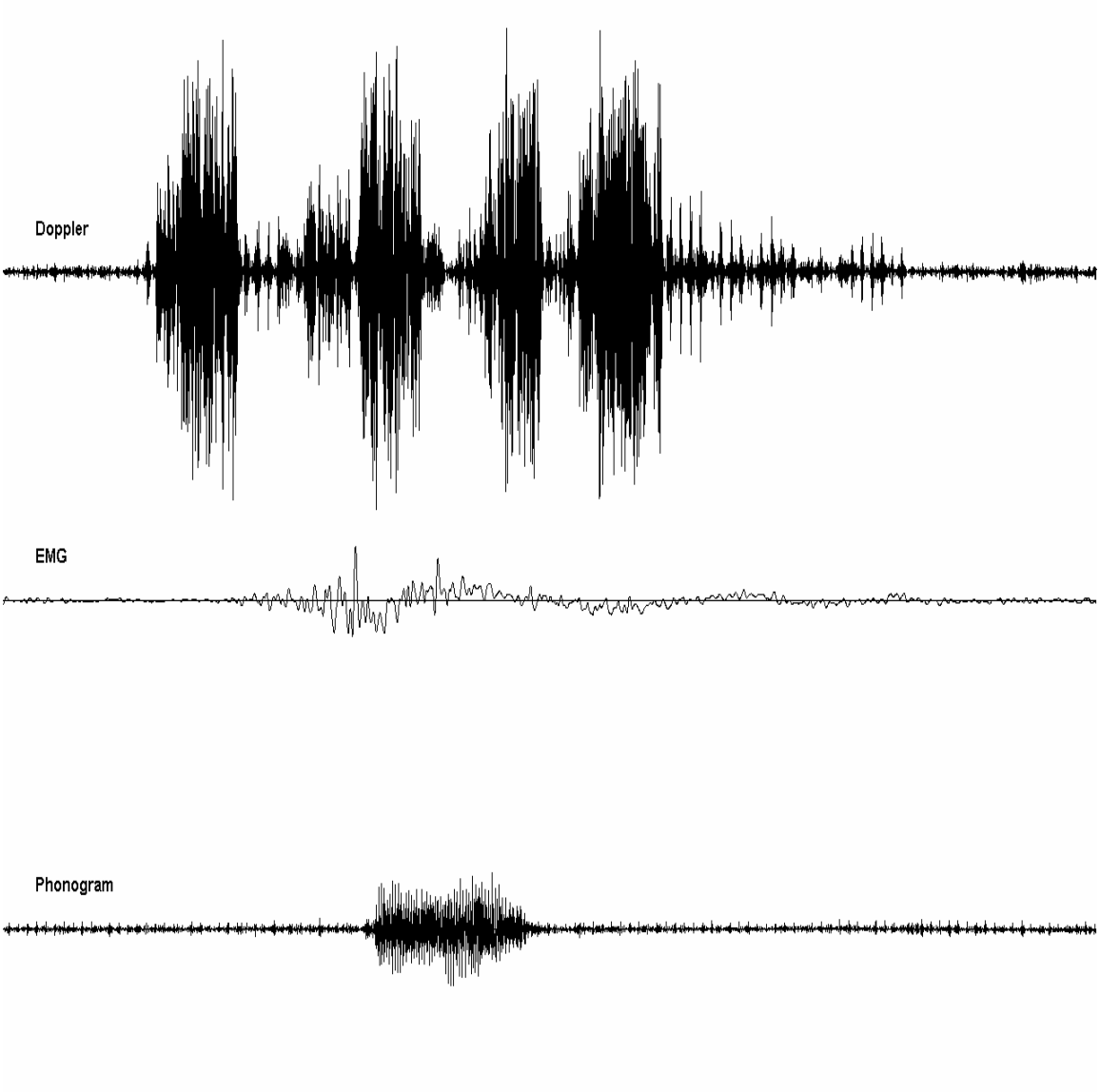

Figure 10. Synchronous recordings of articulation related movement from the tongue (top) and upper lip (middle), and the phonogram for a single spoken utterance of the word “Dog”. Tongue Doppler activity begins 335ms prior to the onset of lip movement and 417ms prior to the phonogram.

Verbal Fluency

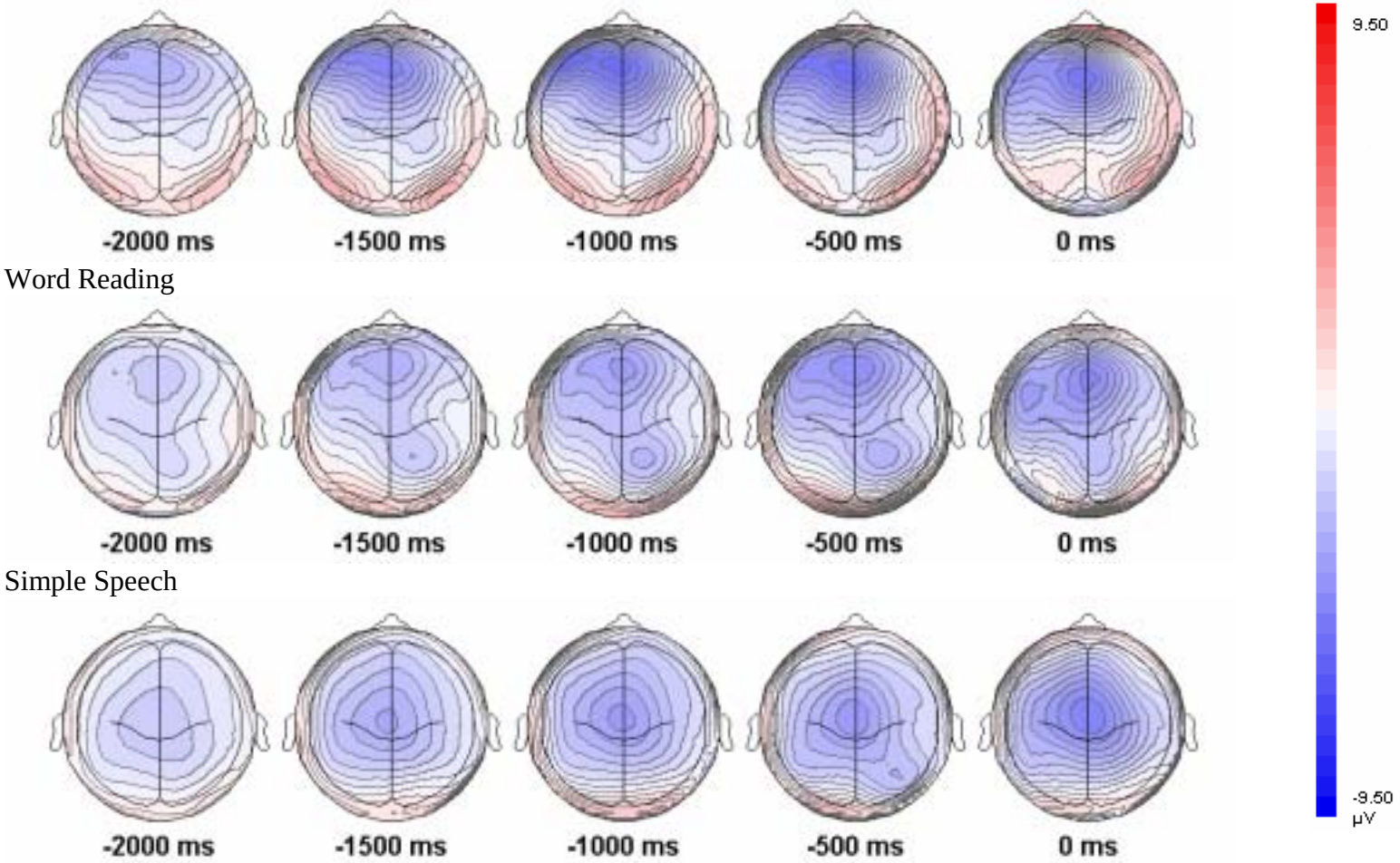

Figure 11. Topographic voltage maps of BP amplitude from -2000ms to speech onset from the verbal fluency, word reading, and simple speech conditions.

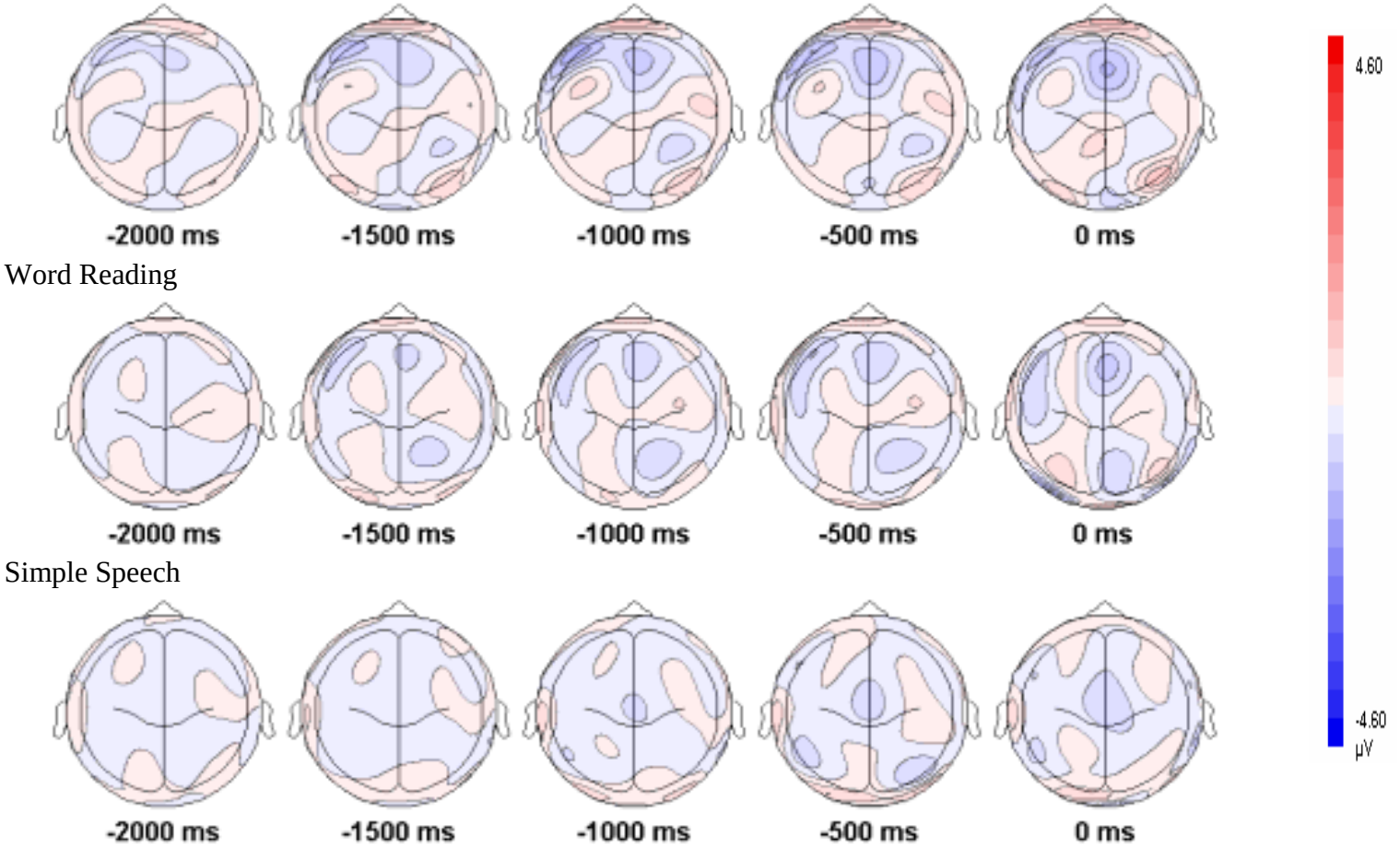

Figure 12. Topographic maps of CSD from -2000ms to speech onset from the verbal fluency, word reading, and simple speech conditions.

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CONSENT TO PARTICIPATE IN A CLINICAL RESEARCH STUDY

MEDICAL RECORD • Adult Patient or • Parent, for Minor Patient

INSTITUTE: National Institute of Deafness and Other Communication Disorders

STUDY NUMBER: 92-DC-0178 PRINCIPAL INVESTIGATOR: Allen R. Braun, M.D.

STUDY TITLE: Functional Neuroimaging Studies of Speech Motor Control and Language Processing

Latest IRB Review: Continuing Review 6/2/05
Latest Amendment Approved: Amend S 11/16/04
Normal Volunteer

INTRODUCTION

We invite you to take part in a research study at the National Institutes of Health (NIH).

First, we want you to know that:

Taking part in NIH research is entirely voluntary.

You may choose not to take part, or you may withdraw from the study at any time. In either case, you will not lose any benefits to which you are otherwise entitled. However, to receive care at the NIH, you must be taking part in a study or be under evaluation for study participation.

You may receive no benefit from taking part. The research may give us knowledge that may help people in the future.

Second, some people have personal, religious or ethical beliefs that may limit the kinds of medical or research treatments they would want to receive (such as blood transfusions). If you have such beliefs, please discuss them with your NIH doctors or research team before you agree to the study.

Now we will describe this research study. Before you decide to take part, please take as much time as you need to ask any questions and discuss this study with anyone at NIH, or with family, friends or your personal physician or other health professional.

Normal Volunteer Consent - Introduction

You are being invited to participate in studies that use radioactive water ($H_2{}^{15}O$) to measure brain blood flow with positron emission tomography or may use other imaging techniques to compare brain function in normal volunteers and patients with disorders of speech and language. In many of these disorders, it is assumed that the brain is functioning differently, although it is not yet clear exactly which areas of the brain are involved.

When a region of the brain is active, it consumes more fuel—in the form of oxygen and glucose— and, in the process, produces more of the waste products carbon dioxide and water. The fuel is delivered, and the waste products are carried off, by the blood.
When activity in a brain region increases, the rate of blood flow in that region also increases—in order to make the delivery of nutrients and the elimination of waste more efficient. In short, the rate of blood flow in an area of the brain is determined by the functional activity—the work—of that area.

This fact can be used in order to study brain activity in living human subjects. Using chemicals which measure blood flow in a positron emission tomography (PET) scanner, we can create maps of regional cerebral blood flow which essentially serve as maps of the brain at work.

We expect that such studies will help us to learn more about how the central nervous system is affected in disorders such as stuttering and other neurological illnesses such as Tourette's syndrome, dystonia, cerebellar disorders, Parkinson's disease and stroke which affect the ability to speak -- and will tell us how brain function is altered by drugs or other forms of therapy used to treat this disorders. You may also be asked to undergo magnetic resonance imaging of the brain as well. All of these procedures will be described in detail below. If they do not apply in your case, this will be indicated (that is, these sections will be crossed out).

This study will take place in the facilities of NIDCD, the Department of Nuclear Medicine and In Vivo NMR Center at the NIH Clinical Center in Bethesda, Maryland. The time required for participating in this protocol will include the following: You may be asked to schedule two clinic visits at which time the medical history, physical examination, training for the PET tasks, speech testing, and screening laboratory evaluations will be performed; each of these visits require 2-3 hours of your time. The PET study itself, including the scans and the insertion and removal of arterial and venous lines, will take approximately 3 hours. If laryngeal procedures are carried out, these add 30 to 60 minutes (preparation time) to the PET procedure. The duration of the MRI studies will vary from 20 minutes to two hours, with most lasting between 45 and 90 minutes.

Procedures

Screening Evaluation and Testing

Before being accepted into the study, you will be seen by a physician who will take a medical history and perform a full physical examination if indicated. If an arterial catheter is to be placed during the PET procedure, you will undergo a brief examination of both wrists (the Allen test) in order to determine that you have the normal double blood supply to your hands. We do this to be sure that your hands would continue to receive an adequate supply of blood should a clot blocking circulation occur.

Women who are pregnant or who are currently breast feeding will be excluded from this study. If you are a woman of childbearing age, you will undergo pregnancy testing (urinary beta-HCG) on the day of the study. If this test is positive, you will not be able to participate.

Magnetic Resonance Imaging

Magnetic resonance imaging (MRI) uses a strong magnetic field and radio waves instead of X-rays to obtain images of body organs and tissues. This technique is more sensitive than X-rays in some circumstances. Since X-rays are not used, there is no radiation exposure.

The MRI scanner is a metal cylinder surrounded by a strong magnetic field. During the MRI, you will lie still on a table that can slide in and out of the cylinder. Scanning time varies from 20 minutes to 3 hours, with most scans lasting between 45 and 90 minutes. You may be asked to lie still for up to 45 minutes at a time. While the scanner takes pictures, you will hear loud knocking noises, and you will wear earplugs to muffle the sound. Individuals with fear of confined spaces may become anxious during this procedure. You will be able to communicate with the MRI staff at all times during your scan, and you may ask to be moved out of the machine at anytime.

Functional MRI involves taking pictures of the brain while performing tasks, such as moving a limb or speaking. All tasks will be explained and you will be given an opportunity to practice before entering the scanner. Functional MRI is conducted without using injections, radioactivity, or x-rays. The MRI machine is able to detect changes in brain regions that are involved in the performance of each specific task. Your fMRI scan will generally take between 1 and 2 hours.

Neurological, Speech-Language and Neuropsychological testing:

At some point, generally before the PET studies are performed, you may undergo a series of tests designed to evaluate cognitive function - that is, tests that measure speech, language, memory and visual skills. The tests will be administered by a trained psychologist or technician and will generally take less than three hours. Portions of these studies, for example those which evaluate speech and language may be video- or audiotaped in order to help us analyze the results. These tapes and the results of these tests will be kept confidential. If you wish, you will receive a written report summarizing these findings and have an opportunity to discuss these with the physician investigators.

Pedigree Interview and Questionnaires

In this study, we may ask you questions by interviewing you or requesting that you complete questionnaires, about your relatives and ancestry. The questions - about handedness, or the presence of medical or neurological symptoms that may run in your family - will be asked to gain neurological information. A pedigree (a family tree in graphic form) will then be drawn to discover a possible pattern or inheritance of handedness or of a disease and to catalog the neurological features associated with it. It is potentially very helpful for us to correlate this information with the results of tests performed regarding other parts of this study.

This part of the study may not provide any direct benefit to you, or your family but may help us better understand certain neurological conditions. The information available at the moment may not be useful for genetic counseling. If the results of this pedigree study provide information that is useful in counseling, we will make it available to you. The pedigree information that will be available from the principal investigator will be information regarding only neurological features or symptoms. In order to maintain confidentiality, we will not give you information about any other person in the study other than your own.

The PET Scan Procedure

For positron emission tomography (PET), a small amount of a radioactive substance is injected into the body through a vein, which can be detected by the PET scanner. The PET scan gives information on brain chemistry and function.

The PET scanner is shaped like a doughnut. You will lie on a bed that slides in and out of the scanner with your head inside the opening. We will custom mold a plastic mask to your face and head. The mask will support your head and prevent it from moving inadvertently during the scan procedures. Most patients do not find the mask uncomfortable.

All PET scans require the placement of an intravenous (i.v.) catheter (a small plastic tube). This catheter will be used for the injection of radioactive water.

Certain studies will involve the use of a second catheter that is inserted into an artery. If you are participating in this type of study, the procedure is described below. If you are not, this material does not apply to you:

The arterial catheter will be placed in an artery at the wrist or elbow crease of one arm following the use of local anesthetic and will be used for blood sampling. If the arterial catheter is to be inserted into the wrist, a simple test will be conducted prior to insertion to ensure that both of the arteries in your wrist are working. A small amount of a local anesthetic (numbing medicine) will be used to numb the skin over the artery. Then, the catheter will be placed in the artery with a needle. The needle will be removed, leaving only the thin catheter in the artery. The catheter will be fastened to the skin with tape. Small samples of blood will be taken from this catheter during the study. The total amount of blood removed will be about 200 milliliters (about a cup). During the time the catheter is in place, you are advised to limit the movement of your arm to avoid displacement of the catheter. A physician or nurse will be available at all times and should be notified immediately if you have pain or discomfort.

Following this, the PET study will begin. A variable number of scans -- lasting about a minute each -- will be carried out. These will be performed while you are at rest or may be associated with a different "task" you will be asked to perform during the course of the scan. These maneuvers may include making simple movements of the arms (this will not occur in subjects who have arterial lines in place) or you may be asked to speak spontaneously, read silently or out loud, sing, or listening to and speaking in accompaniment with recorded sounds. Certain tasks will evaluate your ability to discriminate musical tones or words, or to concentrate and focus your attention. A set of earphones may be used so that these tasks can be performed with minimal movement and without discomfort. The scan session will last between one and three hours.

You may be asked to return for up to three scanning sessions within a single year, but the total radiation dose to which you will be exposed will not exceed the yearly NIH Radiation Safety guidelines for research subjects (see below).

Electrophysiological Studies

Certain of the studies in which you may be asked to participate involve the use of electroencephalographic (EEG/ERP) or brain wave recording techniques. These methods collect information by the use of electrodes which are temporarily attached to the surface of the scalp, or to a cap (resembling a bathing cap) which is placed over the head. It will take about one hour to put on the cap, and one to two hours to perform the tasks in this part of the study. These will consist of visual or auditory stimuli which will be presented to you over a high-resolution computer monitor or through earphones. You may be asked to make simple responses (pressing a button, moving your hand or speaking) in response to these stimuli. Other surface electrodes (EMG) may be used to measure movements of the muscles involved in moving speaking. These electrodes are attached to the skin of the face and neck by plastic or paper tape. These electrodes will be put on by trained professionals and are associated with only minimal discomfort. They will be removed immediately after the studies are completed.

A related method is called magnetoencephalography, or MEG, which is a non-invasive technique for studying brain activity. MEG measures the magnetic fields generated by brain activity by using extremely sensitive detectors that, unlike those used in the other brain wave recordings, are not directly applied to your scalp. In these studies, the shape of your head is measured and you will then be positioned on a recliner located underneath the MEG device. You will be asked to lie still for approximately 1 hour during the experiment. Several electrodes will be briefly attached to your scalp for calibration purposes. These will then be removed and you will listen to sounds or watch visual stimuli while your brain activity is mapped with the MEG device. You may be asked to press a button or to speak out loud in response to sounds, words, or pictures.

STUDY NUMBER: 92-DC-0178 CONTINUATION: page 5 of 8 pages

Risks, Inconvenience, and Discomforts

The medical history, physical examination, EEG, and surface (taped electrode) EMG and MEG recording techniques involve no risk to your health. The cap that may be used to attach the EEG electrodes has occasionally been associated with headache if it fits too snugly, but this is usually relieved by adjusting the cap's position. Participants in the MEG studies may experience some mild discomfort from lying still during data acquisition. However, efforts will be made to position subjects comfortably and to allow rest periods when needed. Routine blood testing which you will undergo prior to the scans is associated only with a slight risk of infection, fainting or bruising at the puncture site. While you may find the speech-language and neuropsychological tests or pedigree interviews frustrating and perhaps stressful, they are not associated with any risk to your health.

Patients are at risk for injury from the MRI magnet if they have pacemakers or other implanted electrical devices, brain stimulators, dental implants, aneurysm clips (metal clips on the wall of a large artery), metallic prostheses (including metal pins and rods, heart valves, and cochlear implants), permanent eyeliner, implanted delivery pump, or shrapnel fragments. Welders and metal workers are also at risk for injury because of possible small metal fragments in the eye of which they may be unaware. You will be screened for these conditions prior to the study, and if you have any of these conditions, you will not receive an MRI scan. If you have a question about any metal objects being present in your body, you should inform the physician. In addition, all magnetic objects (for example, watches, coins, jewelry, credit cards) must be removed before entering the MRI scan room. Women who are pregnant are excluded from MRI. Therefore, all women of childbearing potential will have a pregnancy test performed, which must be negative, before proceeding. You will be asked to complete a MRI screening form, and to sign a separate MRI consent for each MRI.

There are no known long-term risks or consequences of MRI scans.

Some scans may be done in a 3 Tesla (3T) scanner, which is the latest advance in MRI and has a stronger magnetic field than the more common 1.5 Tesla scanners. The FDA has determined that there is no significant risk associated with the 3Tesla MRI. On one occasion, one individual in the 3T scanner reported dryness and a burning sensation in the eyes during a prolonged scan. There was no eye injury, and the burning sensation was thought to be related to a previous dry eye condition. If you suspect that you have a tendency toward eye dryness, you should inform the physician or technician. You will be given the opportunity to wet your eyes with a tear-like saline solution before beginning the scan. If you feel eye discomfort during the procedure, please report this immediately to the technician and the scan will be stopped.

All MRI studies will be conducted with a technician or physician experienced with the use of high strength magnetic fields in attendance. You may stop the study at any time you wish.

No intravenous lines are used in electrophysiological or MRI studies. Intravenous lines are used in all PET studies. The intravenous (i.v.) line which will be placed on the day the PET scans are performed might cause minimal pain when inserted (about the same as the routine blood tests).

Arterial catheters will be occasionally used in some PET studies. Some discomfort is associated with the placement of the arterial needle that may be inserted for the PET studies. Bruising or swelling at the site of the arterial catheter occurs in 5 to 20 percent of patients, but is only temporary. Fainting is remotely possible. Permanent damage from these complications is extremely rare.

There is a rare chance of occlusion (blockage) of the artery by the catheter. To date, two complications have been reported with arterial catheters placed in the wrist, one at the Laboratory of Neurosciences and the second at the

National Institute of Mental Health. In the first case, small radial artery aneurysm developed 2 years after arterial catheterization and was surgically repaired. In the second case, an arterial thrombosis (blockage) of an artery of the hand developed a few days after arterial catheterization and also was repaired surgically. The literature does describe arterial blockage in those who have arterial catheters in place for a long period of time such as for monitoring purposes in an intensive care unit, but not in healthy patients with catheters in place for only a few hours. The worldwide experience with arterial catheterization has shown it to be a safe and reliable method of obtaining arterial blood samples over the few hours necessary for PET studies.

PET studies involve exposure to radiation from the series of radioactive water PET scans and the transmission scans for attenuation correction. Please note that this radiation exposure is not necessary for your medical care and is for research purposes only.

The maximum amount of radiation you will receive in this study is from up to 30 scans of 10 mCi each of radioactive water in a single scanning session, and up to 50 scans over the course of a year. The NIH Radiation Safety Committee has reviewed the use of radiation in this research study and has approved this use as involving slightly more than minimal risk and necessary to obtain the research information desired.

Using the standard way of describing radiation dose, from participating in this study, you will receive a total of 4.65 rem to your heart wall, 4.05 rem to your kidneys and 3.70 rem to your liver.

Although each organ will receive a different dose, the amount of radiation exposure you will receive from these procedures is equal to a uniform whole-body exposure of 2.37 rem. This calculated value is known as the "effective dose" and is used to relate the dose received by each organ to a single value. The amount of radiation received in this study is within the dose guideline established by the NIH Radiation Safety Committee for research subjects. The guideline is an effective dose of 5 rem (or 5,000 mrem) received per year.

For comparison, the average person in the United States receives a radiation exposure of 0.3 rem (or 300 mrem) per year from natural background sources, such as from the sun, outer space, and from radioactive materials that are found naturally in the earth's air and soil. The maximum dose that you would receive from this research study is about the same amount you would normally receive in 7.8 years from these natural sources. If you would like more information about radiation and examples of exposure levels from other sources, please ask the investigator for a copy of the pamphlet called, *An Introduction to Radiation for NIH Research Subjects.*

The effects of radiation exposure on humans have been studied for over 60 years. In fact, these studies are the most extensive ever done of any potentially harmful agent that could affect humans. In all these studies, no harmful effect to humans has been observed from the levels of radiation you will receive by taking part in this research study. However, scientists disagree on whether radiation doses at these levels are harmful. Even though no effects have been observed, some scientists believe that radiation can be harmful at any dose - even low doses such as those received during this research.

One possible effect that could occur at these doses is a slight increase in the risk of cancer. Please be aware that the natural chance of a person getting a fatal cancer during his/her lifetime is about 1 out of 4 (or 25 percent). The increase in the chance of getting a fatal cancer, as a result of the radiation exposure received from this research study, is 0.09%. Therefore, the total risk of fatal cancer may be estimated to increase from 25 percent to 25.09%. This change in risk is small and cannot be measured directly. Compared with other everyday risks, such as flying in an airplane or driving a car, this increase is considered slight.

STUDY NUMBER: 92-DC-0178 CONTINUATION: page 7 of 8 pages

One concern some people may have about radiation exposure is the effect on fertility or on the possibility of causing harm to future children (i.e., genetic risk). The doses you will receive in the study are well below the levels that affect fertility. In addition, genetic effects have not been seen in humans who have been exposed to radiation. The information on genetic effects currently available is based on animal experiments studies using doses of radiation much higher than the amount you will receive in this study.

Please tell your doctor if you have taken part in other research studies or received any medical care at the NIH or other places/hospitals that used radiation. This way we can make sure that you will not receive too much radiation. Consider x-rays taken in radiology departments, cardiac catheterization, and fluoroscopy as well as nuclear medicine scans in which radioactive materials were injected into your body.

If you are pregnant or breast feeding, you may not participate in this research study. It is best to avoid radiation exposure to unborn or nursing children since they are more sensitive to radiation than adults.

The radiopharmaceutical that you will receive is being administered under an Investigational new Drug (IND) approval from the Food and Drug Administration (FDA), with W. Eckelman, Ph.D., as the sponsor; both the sponsor and the FDA have access to the medical records of research subjects.

Because of the extremely short half-life of Oxygen-15, your body will no longer contain significant amounts of radioactivity 10 minutes after the final injection of $H_2{}^{15}O$, and you will pose no exposure risk to yourself or others with whom you come in contact. Therefore, no special precautions regarding personal hygiene or contact will be necessary once you leave the PET Department.

There are no benefits to your health expected from participation in this study. It must also be noted that unforeseeable or unexpected events may occur in the course of these studies. The principal investigator may terminate the study at any time if subjects do not comply with research regulations.

You should understand that you are free to withdraw your consent and discontinue participation in this project at any time. You should also understand that your participation in this study may be ended without your consent if the investigator determines that it is in your best interests of if you significantly fail to follow the study procedures.

Normal volunteers will be compensated on the following basis: imaging studies = $20 for the first hour; $10/per hour thereafter. $10 per inconvenience unit (i.v insertion. = 2 units; arterial line = 3 units; EEG electrodes = 2 units; behavioral/speech testing = 1 unit per session). You will receive reimbursement to cover costs of transportation and lodging, if necessary. Local hotels will be selected from the list provided by the Clinical Center voucher office; flights will be arranged with airlines under government contract. If you are a patient whose participation requires repeated visits to the NIH for PET, fMRI scans or behavioral testing, you will receive additional monetary compensation for participation in this protocol as well. This compensation is meant to cover the costs of taking time off work and/or to mitigate the stress of repeated visits.

If you have any questions or if anything requires clarification, please inform the investigators. No individual who is unable to understand the protocol or give informed consent will be included in this study.

OTHER PERTINENT INFORMATION

1. Confidentiality. When results of an NIH research study are reported in medical journals or at scientific meetings, the people who take part are not named and identified. In most cases, the NIH will not release any information about your research involvement without your written permission. However, if you sign a release of information form, for example, for an insurance company, the NIH will give the insurance company information from your medical record. This information might affect (either favorably or unfavorably) the willingness of the insurance company to sell you insurance.

The Federal Privacy Act protects the confidentiality of your NIH medical records. However, you should know that the Act allows release of some information from your medical record without your permission, for example, if it is required by the Food and Drug Administration (FDA), members of Congress, law enforcement officials, or other authorized people.

2. Policy Regarding Research-Related Injuries. The Clinical Center will provide short-term medical care for any injury resulting from your participation in research here. In general, no long-term medical care or financial compensation for research-related injuries will be provided by the National Institutes of Health, the Clinical Center, or the Federal Government. However, you have the right to pursue legal remedy if you believe that your injury justifies such action.

3. Payments. The amount of payment to research volunteers is guided by the National Institutes of Health policies. In general, patients are not paid for taking part in research studies at the National Institutes of Health.

4. Problems or Questions. If you have any problems or questions about this study, or about your rights as a research participant, or about any research-related injury, contact the Principal Investigator, Allen R. Braun, M.D.; Building 10, Room 5N-118A, Telephone: (301) 402-1497.

You may also call the Clinical Center Patient Representative at 301-496-2626.

5. Consent Document. Please keep a copy of this document in case you want to read it again.

COMPLETE APPROPRIATE ITEM(S) BELOW:

A. Adult Patient's Consent

I have read the explanation about this study and have been given the opportunity to discuss it and to ask questions. I hereby consent to take part in this study.

Signature of Adult Patient/Legal Representative _____ Date _____

B. Parent's Permission for Minor Patient.

I have read the explanation about this study and have been given the opportunity to discuss it and to ask questions. I hereby give permission for my child to take part in this study.
(Attach NIH 2514-2, Minor's Assent, if applicable.)

Signature of Parent(s)/Guardian _____ Date _____

C. Child's Verbal Assent (If Applicable)

The information in the above consent was described to my child and my child agrees to participate in the study.

Signature of Parent(s)/Guardian _____ Date _____

THIS CONSENT DOCUMENT HAS BEEN APPROVED FOR USE FROM APRIL 28, 2005 THROUGH APRIL 28, 2006.

Signature of Investigator _____ Date _____ Signature of Witness _____ Date _____

Curriculum Vitae

May 2006

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EDUCATION

2006 PhD, Psychology
Virginia Polytechnic Institute & State University
Blacksburg, Virginia
Dissertation: Semantically based lexical processing yields unique topographic contributions to the speech Bereitschaftspotential.

1999 M.A. General Psychology, Concentration in Cognition and Electrophysiology
University of West Florida
Pensacola, Florida
Thesis: Comparing Expert Meditators to Non-meditating Control Using Two Types of Meditation And Two Cognitive Tasks: An ERP Study.

1996 B.S. in Psychology, Minor in Counseling and Guidance
Magna Cum Laude
University of Montevallo
Montevallo, Alabama
Honors thesis: Mediation of responses to threatening information: The psychology of environmental destruction

PROFESSIONAL ASSOCIATIONS

Student Affiliate of the American Psychological Association
Student Affiliate of the Association for the Advancement of Behavior Therapy
Student Affiliate of Southeastern Psychological Association
Student Affiliate of Cognitive Neuroscience Society

HONORARY ORGANIZATIONS

Psi Chi, National Psychology Honorary
Phi Kappa Phi, National Honor Society
Omicron Delta Kappa, National Leadership Honor Society

RESEARCH RELATED EXPERIENCE

Beta tester of the 128-channel Neuroscan EEG/ERP work station, 1996-1998, UWF
Experience with 24 channel Lexicor system and grass amplifiers
Operation of 1.5 and 3T GE fMRI scanners: collection, analysis and interpretation of fMRI data.

Operation of CTF Magneto-Encephalograph system, a whole-head SQUID magnetometer with 275 channels
Doppler imaging of the tongue

WORK EXPERIENCE

National Institute of Communication Disorders and Deafness, National Institutes of Health:
Post-Doctorial IRTA Fellow beginning July 2006.
Pre-Doctorial IRTA Fellow Fall 2002 to 2006.
Professional Contract Employee, Fall 2001 to 2002.
Summer Internships- 2000-2001.
Displays and Controls Lab, Department of Industrial and Systems Engineering, Virginia Tech:
Conducted behavioral research for LG electronics, Summer 1999
Department of Psychology, Virginia Tech:
Web-site development, 1998-1999.
Neurocognition Laboratory, University of West Florida:
Research assistant, 1996-1998.
Psychology Department, University of West Florida:
Web-site development, 1997.

TEACHING EXPERIENCE

Learning Psychology, Virginia Tech, Spring 2000, Fall 2000, and Spring 2001
Cognitive Psychology Lab, Virginia Tech, Fall 1999
Experimental Psychology Lab, University of West Florida, Spring 1997.

PUBLICATIONS

McArdle, Joseph (1999). Precis of "Sleep problems? Counting pills instead of sheep" by Cartwright, R. D. (1974). In Helena K. Chandler and Jack W. Finney (Eds.), Exploring introductory psychology: A reader and workbook (pp. 95-96). New York: McGraw-Hill, Inc.

McArdle, Joseph (1999). Precis of "Analysis of dream content" by Haimov, I., & Lavie, P. (1996). In Helena K. Chandler and Jack W. Finney (Eds.), Exploring introductory psychology: A reader and workbook (pp. 109-110). New York: McGraw-Hill, Inc.

PRESENTATIONS

McArdle, Joseph, J., Mari, Zoltan & Braun, Allen, R., (2004). Language complexity produces unique topographic contributions to the Bereitschaftspotential. Presented at the 11th conference of the Cognitive Neuroscience Society.

V.B. Nechaev , J. Xu , G. Park , C. Frattali, J. McArdle , A. Braun. Processing of open and closed class words at word, sentence and narrative levels: an ERP study. Presented at Human Brain Mapping 2003.

V.B. Nechaev, J. McArdle, C. Frattali, A.R. Braun. ERP-Correlates of Modality Dependent and Independent Knowledge. Presented at the Society for Neuroscience conference 2003.

V.B. Nechaev, J. McArdle, A.R. Braun ERP-Correlates of Modality Dependent and Independent Semantic Processing. Presented at Cognitive Neuroscience conference 2003.

McArdle, J. J., Dunn, B. R., & Mikulas, W. L. Comparing experienced meditators to controls across two attentional strategies: An ERP study. Presented at the 2000 annual meetings of the American Psychological Association.

McArdle, J. J., Daugherty, S., & Crawford, H. J. Earlobes vs. nose reference: Differential impact on auditory and visual odd-ball ERP's. Presented at the 2000 annual meeting of the American Psychological Society.

McArdle, J. (1996). Assessing differential expectations of effective college teachers: the role of gender of target and of subject. Presented at the Eleventh Undergraduate Psychology Student Research Association's conference for 1996.

Croney, H & McArdle, J. (1995). Mediation of Responses to Threatening Information: The Psychology of Environmental Destruction. Presented at CEPO Undergraduate Session of the Southeastern Psychological Association for 1995 and at the Tenth Undergraduate Psychology Student Research Association's conference
for 1995.