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## Topographic differences in CNV amplitude reflect different preparatory processes

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### Abstract

Topographic differences in Contingent Negative Variation (CNV) were recorded while people were preparing for cognitive versus motor tasks in an S1–S2 paradigm. CNV had a frontal distribution when people prepared to encode words into long-term memory, whereas CNV was more centrally distributed when the tasks were predominantly motoric. These topographic differences appeared to be related to the type of task rather than the amount of information extracted from the S2, because a direct manipulation of the level of S2 processing had little effect on CNV amplitude. The topographic differences in CNV suggest that preparation for motor activity is a different psychological process from preparation for stimulus processing and that these two processes are subserved by different neural structures. This experiment also demonstrated that a recognition memory paradigm can be useful in the investigation of the psychological correlates of CNV. © 1998 Elsevier Science B.V. All rights reserved.

*Keywords:* Event-related potentials; Contingent Negative Variation; Preparation; Cognitive tasks; Motor tasks

### 1. Introduction

When a task is preceded by a warning stimulus, people are able to prepare for the task and the response time is usually reduced (Requin et al., 1991; Pashler, 1994). The psychological process of preparation is also accompanied by reliable changes in brain activity as measured by event-re-

lated brain potentials (ERPs). A slow, negative ERP potential is recorded during the interval between the warning signal (S1) and the imperative stimulus (S2), as long as the task has some relevance to the participant (Walter et al., 1964).

This negative potential is called Contingent Negative Variation (CNV) and it appears to have two major components (i.e. early and late) which reflect different psychological processes that occur during the interval between the warning signal and the imperative stimulus (i.e. the foreperiod). Early CNV is primarily found over the

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frontal lobes and appears to reflect the processing of the warning signal (Rohrbaugh and Galliard, 1983). In contrast, late CNV usually has central–parietal location and appears to reflect preparation (Damen and Brunia, 1994).

The specific type of preparation that CNV reflects is debated because the tasks that are used to investigate CNV typically require a movement of some kind (e.g. a key press). Preparation for a motor response is accompanied by another ERP, called a readiness potential (RP), that is very similar to CNV. The RP is distinctly visible just before people perform self-paced movements (i.e. when the movements are not signalled) and most cued movements. Both CNV and the RP tend to be localized at central sites, visible over both hemispheres, and largest over the contralateral hemisphere before finger movements (e.g. Brunia and Damen, 1988). The similarities of the two potentials have led some researchers to conclude that CNV merely reflects activation of the motor cortex just prior to a movement and is, therefore, identical to the RP (Rohrbaugh et al., 1976; Rohrbaugh and Galliard, 1983). Others, however, contend that CNV is an amalgam potential comprised of a RP superimposed on another negative potential that reflects preparation for stimulus processing (Tecce, 1972; Tecce and Cattanach, 1993; Damen and Brunia, 1994). Preparation to process a stimulus (hereafter cognitive preparation) is difficult to separate from motor preparation because responses (involving motoric activity) allow an experimenter to monitor participants' performance. Despite this difficulty, several paradigms have attempted to investigate multiple types of preparation.

Böcker et al. (1994) evaluated scalp-current source density fields recorded before a voluntary movement (i.e. RP) and before a warned movement (i.e. CNV) to address this issue. The density fields for these two tasks were different, even though the scalp fields were not. Current sinks over the parietal cortex preceding the warned reaction time task, but not voluntary movements, suggest that CNV contains an extra source component related to the processing of the imperative stimulus.

Motor and cognitive preparation have been

temporally separated by delaying the motor response (e.g. Ruchkin et al., 1995) or by a feedback paradigm (e.g. Lacey and Lacey, 1973, 1974; Damen and Brunia, 1987). In a typical feedback paradigm, a warning stimulus signals the duration of the interval to be estimated. Participants press a key when they believe the interval has elapsed, and a few seconds later they receive feedback on the accuracy of their temporal estimation. Therefore ERPs preceding the motor response reflect motor preparation and ERPs preceding the feedback stimulus reflect cognitive preparation.<sup>1</sup>

In addition to these approaches, CNV has been observed in a variety of different paradigms when the motor requirements of the task were eliminated (Cohen and Walter, 1966; Donchin et al., 1972; Tecce, 1972; Simmons et al., 1979; Klorman and Ryan, 1980; Tecce and Cattanach, 1993). These results suggest that parts of CNV reflect cognitive preparation. However, eliminating the motor requirements of the task makes monitoring participants' psychological state difficult. In the present experiment, a recognition memory paradigm eliminates the need for a motor response and allows participants' performance to be monitored. In this paradigm, participants prepare to encode words into long-term memory to examine cognitive preparation. Successful encoding can be verified after the study sequence via a memory test. This approach is valuable because it can extend the growing body of evidence suggesting portions of CNV are related to preparation for cognitive activity, with the additional benefit that recognition data can further our understanding of preparatory processes.

One important difference between the motor and cognitive tasks is the amount of information that participants extract from the S2. A cognitive

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<sup>1</sup>The potentials which occur prior to the feedback stimulus were named stimulus preceding negativity (SPN) by Brunia, Damen, and their colleagues. These potentials are very similar to non-motor CNV observed in S1–S2 paradigms that do not require a motor response. The SPN designation refers to ERP activity prior to feedback, whereas CNV usually refers to ERP activity that precedes the imperative stimulus. Even though SPN has a different name, it probably reflects a similar cognitive preparatory process as *non-motor* CNV.

task would appear to require extracting more information in addition to the execution of a cognitive task. For this reason, the present experiment investigated the effects of the depth of S2 processing on CNV amplitude. In a shallow task, participants were asked use the surface features of the stimulus to respond appropriately, whereas a deep task required more information to be extracted from the S2 to respond accurately. If the level of processing does not affect CNV amplitude, then any preparatory ERP differences observed between motor and cognitive tasks cannot be simply attributed to the quantity of information extracted from the imperative stimulus. Therefore manipulating the level of processing can separate preparatory differences due to the nature of the task (i.e. cognitive vs. motor) from the amount of information extracted from the S2.

## 2. Method

### 2.1. Participants

Twelve University of Georgia students (8 males, 4 females), aged 17–22 years, volunteered in exchange for course credit. All participants reported that they were right-handed, had normal or corrected-to-normal vision, and did not have a history of neurological disease.

### 2.2. Apparatus

The participants sat in a recliner located in a sound attenuated, electrically shielded chamber facing a VGA computer monitor located 110 cm away. Each character presented on the monitor extended 0.4° of visual angle vertically and horizontally. The chamber was dimly lit with one 10-W DC light. A white noise generator was used to obscure any transient auditory noise that might be heard during the experiment. People were monitored by closed circuit television with a two-way communication system. Motoric responses were recorded on a computer keyboard located on the arm rests of the recliner.

### 2.3. Procedure

Each participant performed four tasks.<sup>2</sup> In all four tasks, the trial sequence was as follows: the warning stimulus (S1) was presented for 300 ms in the center of the monitor, a blank screen appeared for 3700 ms during the foreperiod, and then the imperative stimulus (S2) was presented. The S2 was presented for a duration of 300 ms in the cognitive tasks (described below), but remained on the monitor in the motor tasks (described below) until the participants responded. The screen was black for a random 5–7 s during the response period, or inter-trial interval (ITI). Rest breaks, lasting 8 s, occurred after every 50th trial.

The S1 in the choice RT task was the word 'ARROW' and the S2 was two pound signs (##) presented on either the left-hand or right-hand side of the monitor. People were instructed to press the left arrow key (←) on the keyboard when S2 appeared on the left side of the screen and to press the right arrow key (→) when the S2 appeared on the right. Both arrow keys were located on the right side of the keyboard, and all participants were instructed to press the left arrow key with their right-hand index finger and to press the right arrow key with their right-hand middle finger as quickly as possible. In the simple RT task, the S1 was the word 'DOWN' and the S2 was the word 'NOW'. Participants were instructed to press the down arrow key (↓) on the keyboard with their right-hand index finger as soon as the S2 appeared.

The third and fourth tasks were more cognitively demanding and did not have any motor requirement. The S1 in the third task was the word 'SPELL' and the S2 was a five-letter English

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<sup>2</sup>The participants completed a fifth task in the experiment. The S1 on that task was the word 'PASS' and the S2 was a string of five letters (e.g. 'XRTEG'). Participants were instructed to ignore the S2. In an early review of this article, a reviewer emphasized that it is impossible to know exactly what participants were doing on these trials. Consequently, the discussion of this task was eliminated from the article.

word. In the fourth task, the S1 was the abbreviation 'SYNANT' and the S2 was also a five-letter English word. The word stimuli in these tasks came from a pool of 100 five-letter words with 50 or more occurrences per million (Francis and Kučera, 1982), and each word in the pool had an equal probability of serving in each of the two cognitive tasks. Participants were instructed to mentally spell the words in the spell task, to think of an associate in the syn/ant task, and specifically instructed not to verbalize their responses.

The presentation order for the four types of tasks, the location of the S2 (in the choice RT condition only), and the word order in both the spell and syn/ant tasks were completely randomized across trials for each participant. Fifty trials of each task were presented, totalling 200 trials for each participant.

#### 2.4. Behavioral responses

Participants in this experiment responded motorically (with key presses) in the choice RT and simple RT tasks, and their reaction time and accuracy were recorded by a computer. Participants were instructed to mentally spell words in the spell task and to think of an associate for the words in the syn/ant task, therefore no behavioral responses for these two tasks were recorded during experimental trials while EEG was sampled. A 200-item recognition memory test for these words was administered at the conclusion of the 200 experimental trials. One-hundred words on the test were new, 50 words were used in the spell task, and 50 words were used in the syn/ant task. Participants were instructed to circle all the words they had observed in the experiment. The percentage of correct responses was computed for all tasks, and average reaction times were computed for the choice RT and simple RT tasks.

#### 2.5. Recording procedures

Eight Ag/AgCl electrodes were attached to the prefrontal scalp (Fp1, Fp2), frontal scalp (F3, F4), central scalp (C3, C4) and parietal scalp (P3, P4). This montage was referenced to the left earlobe on-line and later recalculated off-line to produce

an average reference (Nunez, 1981). The electrooculogram (EOG) was recorded bipolarly using two 4-mm Ag/AgCl recessed electrodes affixed with adhesive collars. One electrode was attached 3 cm directly above the participant's right pupil, while the other electrode was attached laterally below the right eye (cf. Damen and Brunia, 1994). All electrode sites were cleansed with Nuprep to reduce interelectrode impedance below 3 k $\Omega$ . Ten20 conductive paste served as the electrolyte. EEG and EOG signals were recorded with a Contact Precision Instruments amplifier with the high pass filter set to 0.01 Hz ( $-3$  dB attenuation; 16 s time constant) and the low pass filter set to 40 Hz ( $-3$  dB). A 60-Hz notch filter ( $-50$  dB) was used to reduce electrical noise. EEG and EOG were sampled 100 times per second for 4.8 s on each trial: for 500 ms before S1, for the 300-ms S1 duration, during the 3700-ms foreperiod, and for 300 ms during the S2 presentation.

#### 2.6. Signal analysis

Trials were corrected for eye movement artifacts using the algorithm of Semlitsch et al. (1986).<sup>3</sup> The data were digitally filtered off-line to a 0.01–5-Hz bandpass using a zero-latency shift filter (highpass rolloff  $-24$  dB/octave and low-pass rolloff  $-98$  dB/oct). Trials with voltages in excess of  $\pm 75$   $\mu$ V were automatically excluded from averaging by the computer (on average 19% of the total trials were eliminated).

CNV amplitudes were measured by computing the average amplitude for three 400-ms latency ranges relative to the average activity in the 500-ms pre-S1 epoch. These latency ranges were as follows: early CNV (800–1200 ms post-S1 onset), middle CNV (2000–2400 ms post-S1) and late CNV (3600–4000 ms post-S1). These ranges are

<sup>3</sup>The effects observed in the syn/ant task have been replicated in two additional experiments (two separate articles in preparation) that corrected EOG using the algorithm developed by Berg and Scherg (1994). Therefore these effects appear to be reliable and relatively insensitive to the type of EOG correction method employed.

consistent in size and temporal location with previous research that reports that early CNV begins approx. 800 ms after the warning signal and that late CNV starts a few hundred milliseconds before the imperative stimulus (Damen and Brunia, 1994).

### 2.7. Experimental design

The data for each time interval were analyzed separately with an ANOVA model that contained four within-subject factors. The factors in each analysis were Task (spell, syn/ant, choice RT, simple RT), Electrode Position (frontal pole, frontal, central, parietal) and Hemisphere (left, right). Post-hoc ANOVA models were used to evaluate significant main effects. To correct for potential violations of the sphericity assumption of these models, degrees of freedom were corrected by multiplying the original degrees of freedom by the Hundt–Feldt epsilon and truncating the product to an integer. The uncorrected degrees of freedom along with the Hundt–Feldt epsilons are reported in the results sections of these two experiments. To properly evaluate Task  $\times$  Electrode interactions, the data were transformed according to the first correction procedure outlined by McCarthy and Wood (1985).

## 3. Results and discussion

### 3.1. Behavioral data

Although responses were not recorded on a trial by trial basis during the spell and syn/ant tasks, participants clearly recognized the words that were presented during these trials (% hits = 62.83, S.D. = 13.99; % false alarms = 6.33, S.D. = 5.57). Participants appeared to follow the instructions to spell words mentally in the spell task and to think of an associate in the syn/ant task because recognition was better for the words in the syn/ant task (mean = 71.83, S.D. = 12.28) as compared to the words in the spell task (mean = 53.83, S.D. = 17.49;  $t_{11} = 5.46$ ,  $P < 0.001$ ). This is a standard level of processing result in the memory literature (e.g. Craik and Lockhart, 1972). Com-

pared to the cognitive tasks, the choice RT task (mean = 99.17, S.D. = 1.59) and the simple RT task (mean = 99.83, S.D. = 0.58) were much less demanding. The choice RT task, however, took longer to complete (mean = 423 ms, S.D. = 130) than the simple RT task (mean = 338 ms, S.D. = 75;  $t_{11} = 3.22$ ,  $P = 0.008$ ). Thus, participants appeared to follow our instructions carefully.

### 3.2. ERP data

The grand average ERPs for each task are displayed in Fig. 1 with negative voltage up on the  $y$ -axis. The bold lines represent the two motor tasks (choice RT and simple RT), whereas the thin lines represent the cognitive tasks (spell and syn/ant). The two tasks that involved deep processing of the imperative stimulus (choice RT and syn/ant) are graphed with a solid line, and the two shallow tasks (simple RT and spell) are depicted with a dotted line. The analysis of the ERP data are reported separately for early CNV (800–1200 ms post-S1), middle CNV (2000–2400 ms post-S1) and late CNV (3600–4000 ms post-S1) amplitude measures. Fig. 2 plots the three amplitude measures and the standard error of the mean at each electrode site as a function of the type of task.

#### 3.2.1. Early CNV (eCNV)

The omnibus test of eCNV amplitude measures revealed that the activity differed from the front to the back of the scalp (Electrode Position:  $\epsilon = 0.48$ ,  $F_{3,33} = 4.48$ ,  $P < 0.05$ ,  $\eta^2 = 0.29$ ). Table 1 displays the mean ERP activity for each level of electrode position for all three amplitude measures. Post-hoc analysis of this effect revealed that the central sites were more negative than the frontal poles ( $F_{1,11} = 8.08$ ,  $P = 0.02$ ) and the frontal sites ( $F_{1,11} = 7.01$ ,  $P = 0.02$ ). None of the other main effects or interactions (Task, Hemisphere, Task  $\times$  Electrode Position, Task  $\times$  Hemisphere) in the omnibus analysis was significant ( $F < 3$ ,  $P > 0.1$ ). The absence of topographic or amplitude differences in early CNV is consistent with previous research (e.g. Rohrbaugh and Galliard, 1983) because the factors that affect

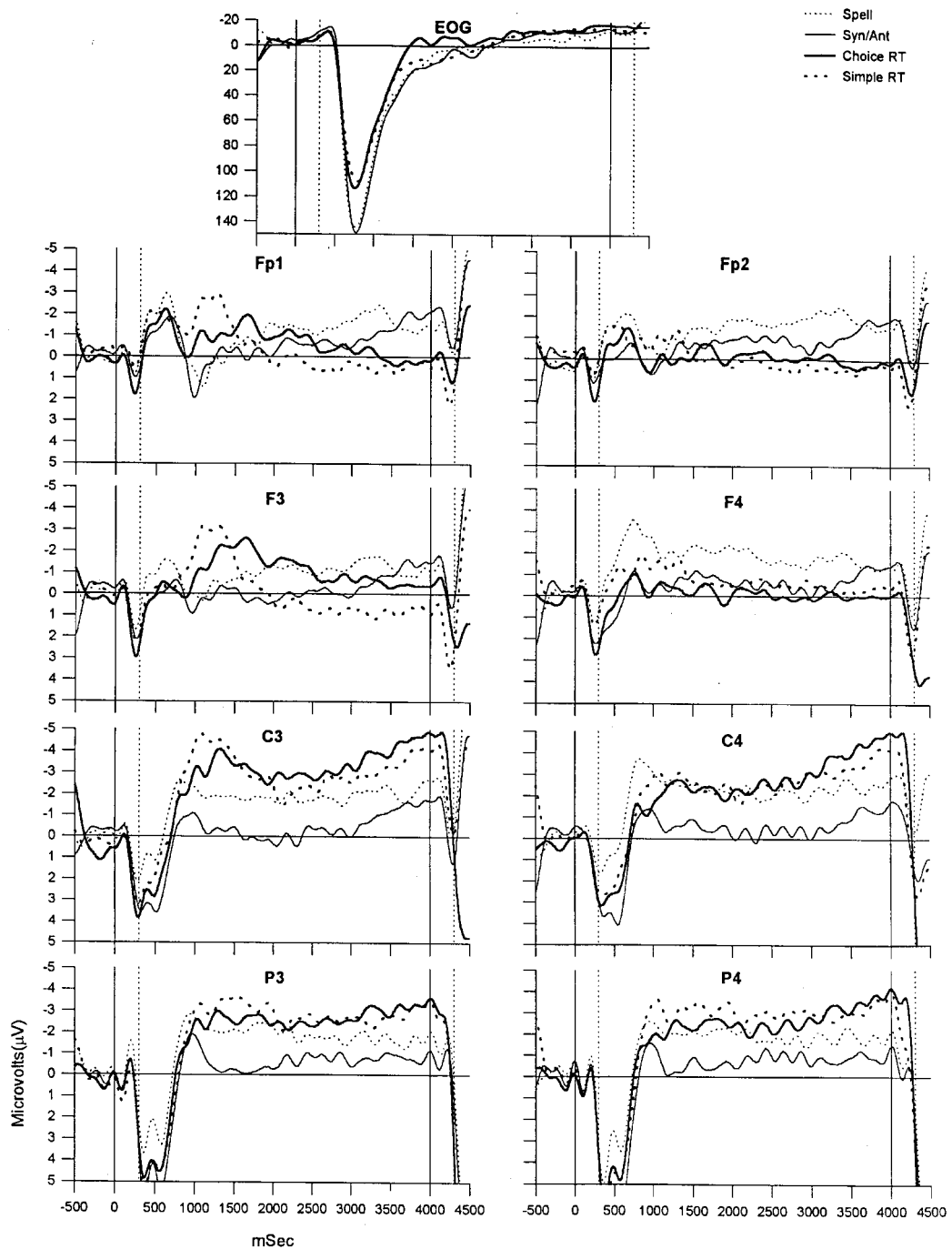


Fig. 1. Grand average ERPs for the four tasks. The ERP activity at each electrode for the five tasks are displayed in a separate graph. The bold lines represent the two motor tasks (choice RT and simple RT), whereas the thin lines represent the cognitive tasks (spell and syn/ant). The thin broken line represents the control task. The two tasks that involved deep processing of the imperative stimulus (choice RT and syn/ant) are graphed with a solid line. Anterior sites are positioned toward the top of the figure, and left hemisphere electrodes are displayed on the left, whereas ocular activity is displayed in the top center graph. The solid vertical bars represent the onset of the warning (S1) and imperative stimulus (S2), whereas the dotted lines represent stimulus offset.

eCNV (i.e. perceptual quality and information content of the warning signal) were constant across tasks.

### 3.2.2. Middle CNV (mCNV)

The omnibus test of mCNV amplitude measures revealed an interaction between Task and Electrode Position ( $\epsilon = 0.45$ ,  $F_{9,99} = 2.90$ ,  $P < 0.05$ ,  $\eta^2 = 0.21$ ) that suggested the four tasks differed in ERP topography. The effects of Task, Hemisphere, Electrode Position, and the interaction between Task and Hemisphere were not significant (all  $P > 0.05$ ). To explain the significant Task  $\times$  Electrode Position interaction, the two cognitive tasks (syn/ant and spell) were compared to one another using a post-hoc ANOVA. The Task  $\times$  Electrode effect was not significant in this post-hoc analysis ( $F_{3,33} = 1.28$ ,  $P > 0.2$ ). Likewise, the ERP topography of two motor tasks (choice RT and simple RT) was similar (Task  $\times$  Electrode Position:  $F_{3,33} = 2.57$ ,  $P > 0.1$ ). Consequently, the two cognitive tasks were pooled together and compared in a third post-hoc test to the pooled motor tasks. The Task  $\times$  Electrode Position was significant in this analysis ( $\epsilon = 0.5$ ,  $F_{3,33} = 5.81$ ,  $P < 0.05$ ) suggesting that preparation for a motor task produced a pattern of ERP activity that was different from the pattern produced by preparation for a cognitive task. Fig. 3, which plots the mean ERP activity in the two cognitive tasks (solid line) vs. the mean ERP activity in the two motor tasks (dotted line), clearly illustrates this topographic difference. Preparation for the cognitive tasks was accompanied by greater (i.e. more negative) mCNV amplitudes at frontal pole sites, whereas preparation for the motor tasks was accompanied by greater negativity at central-parietal sites.

### 3.2.3. Late CNV (lCNV)

The results of the lCNV analysis were similar to those of the mCNV. There was an interaction between Task and Electrode Position ( $\epsilon = 0.53$ ,  $F_{9,99} = 9.29$ ,  $P < 0.001$ ,  $\eta^2 = 0.46$ ) which suggested that the tasks differed in ERP topography. As in the previous analysis, the two cognitive tasks (syn/ant and spell) were compared to one another and the two motor tasks were compared to

one another to examine the omnibus Task  $\times$  Electrode interaction. No significant effects were obtained in either of these two analyses (all  $P > 0.05$ ) suggesting that tasks involving similar processing produced similar ERP topographies. Thus, the two cognitive tasks were pooled together and compared in another post-hoc test to the pooled motor tasks. The Task  $\times$  Electrode Position interaction ( $\epsilon = 0.74$ ,  $F_{3,33} = 26.47$ ,  $P < 0.001$ ,  $\eta^2 = 0.7$ ) suggested that preparation for motor tasks produced a different pattern of ERP activity than preparation for cognitive tasks. Fig. 3 shows that at central sites CNV was greater for the motor tasks but greater for the cognitive tasks at the frontal pole sites.

The omnibus effect of Electrode Position was also significant suggesting that the lCNV amplitudes differed from the front to the back of the scalp ( $\epsilon = 0.67$ ,  $F_{3,33} = 10.42$ ,  $P < 0.01$ ,  $\eta^2 = 0.49$ ). Post-hoc tests that examined the Electrode Position factor (see Table 1) revealed that ERPs at the central sites were more negative than the ERPs at the frontal poles ( $F_{1,11} = 10.68$ ,  $P = 0.007$ ) as well as ERPs at the frontal sites ( $F_{1,11} = 20.80$ ,  $P = 0.001$ ). Likewise, ERPs at the parietal sites were more negative than they were at the frontal poles ( $F_{1,11} = 7.16$ ,  $P = 0.022$ ) and the frontal sites ( $F_{1,11} = 12.42$ ,  $P = 0.005$ ). None of the other factors in the omnibus test (Task, Hemisphere, Task  $\times$  Hemisphere) was significant (all  $F < 1$ ).

### 3.3. Summary

According to the statistical analyses, the activity early in the foreperiod was similar across all experimental tasks, but the cognitive tasks differed in topography from the motor tasks beginning around the middle of the foreperiod. These effects are probably not attributable to ocular activity because the raw EOG activity was not significantly different across the tasks for eCNV ( $F_{3,33} = 1.17$ ), mCNV ( $F_{3,33} < 1$ ), or lCNV measures ( $F_{3,33} < 1$ ). As illustrated in both Figs. 1 and 2, the two cognitive tasks were similar to one another and the two motor tasks were similar to one another. Also visible in these figures is the topographic difference late in the foreperiod

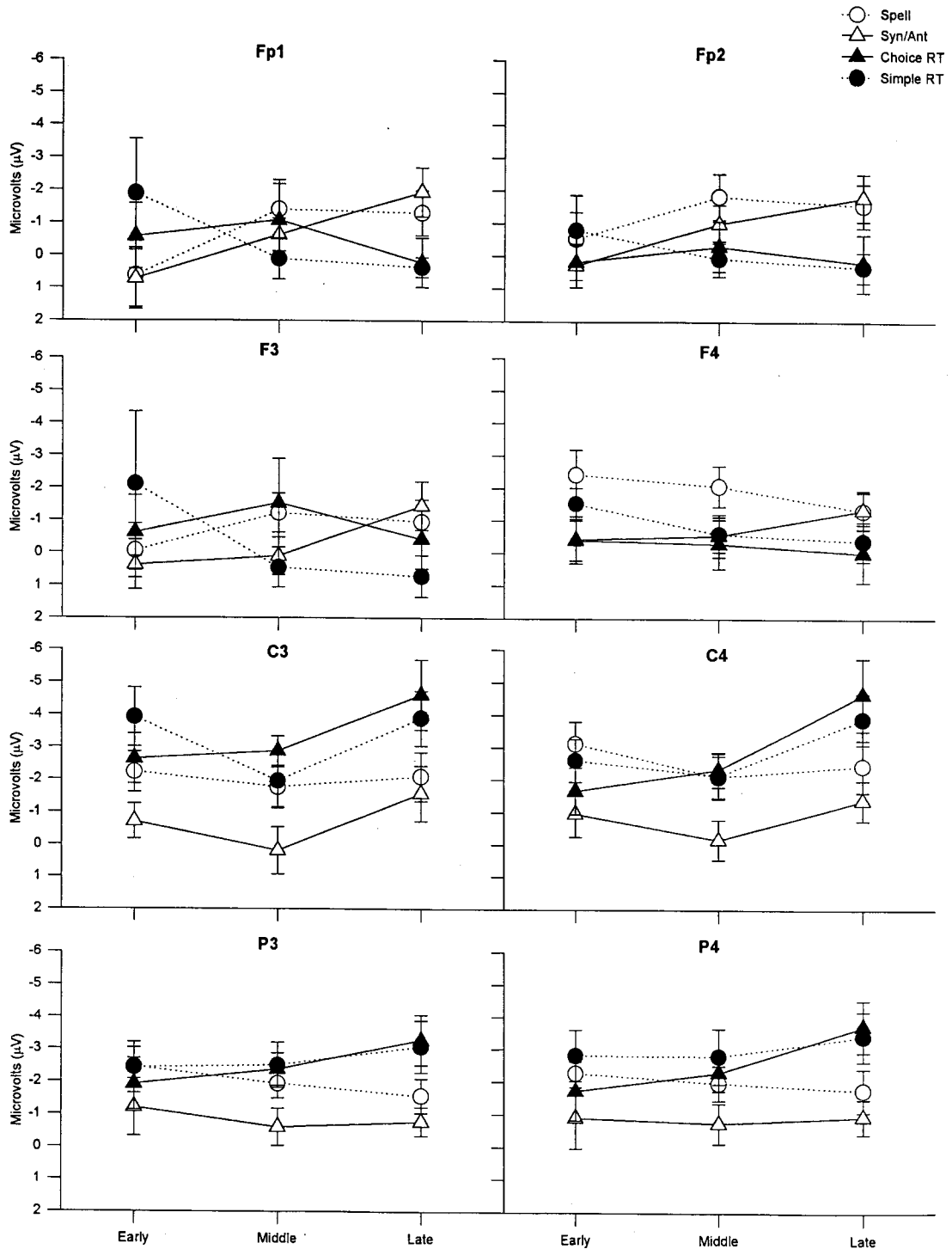


Fig. 2. The mean ERP voltage plotted over the three time-intervals (800–1200, 2000–2400 and 3600–400 ms post-S1 onset) as a function of task type. The two cognitive tasks are depicted with white circles (spell) or triangles (syn/ant) connected with a dotted line, whereas the motor tasks are represented with black circles (simple RT) or triangles (choice RT) connected with a solid line. Error bars represent standard error of the mean.

Table 1  
Mean ERP activity collapsed across Task and Hemisphere

Electrode position	eCNV	mCNV	ICNV
Frontal Pole (FP1/2)	-0.25 (0.54)	-0.76 (0.46)	-0.69 (0.43)
Frontal (F3/4)	-0.90 (0.49)	-0.72 (0.37)	-0.65 (0.42)
Central (C3/4)	-2.24 (0.47)	-1.64 (0.39)	-3.06 (0.60)
Parietal (P3/4)	-1.97 (0.56)	-1.90 (0.36)	-2.31 (0.45)

Note. The values in parentheses are standard error of the mean.

between the cognitive vs. the motoric tasks. Preparation for motor tasks resulted in maximal CNV at central sites, but preparation for cognitive tasks also produced a frontal negative CNV not observed before the motor tasks. Additio-

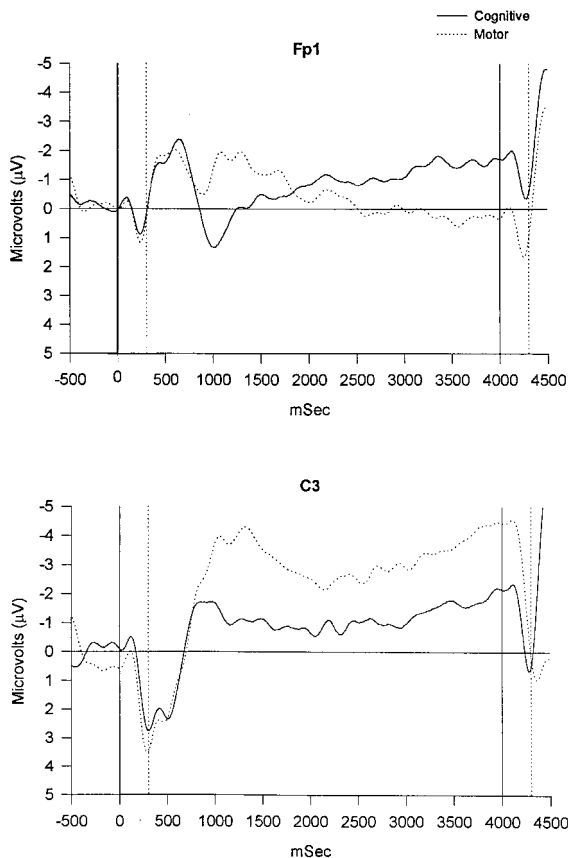


Fig. 3. Grand average ERP activity collapsed across type of task (cognitive and motor) at Fp1 and C3 electrode sites. This figure clearly illustrates the difference in ERP topography across these two general types of tasks.

nally, the amount of information extracted from the imperative stimulus (level of processing) had little effect on CNV amplitude, suggesting that the nature of the task (cognitive or motor) to be performed was more important than the amount of information extracted from the S2. Taken together, these results support the claim that cognitive preparation is a different psychological process from motor preparation.

#### 4. Discussion

The primary goal of this article was to provide separate records of brain activity during motoric and cognitive preparation. To accomplish this goal, two experimental tasks required a motor response (i.e. a key press) to the imperative stimulus, whereas the motor response requirement was eliminated in two additional tasks to observe cognitive preparation. Additionally, the amount of information to be extracted from the S2 (i.e. level of processing) was manipulated to disambiguate CNV differences due to the nature of the task (cognitive vs. motor) from differences due to the depth of processing. The ERP topographies were unaffected by the level of processing, but they differed for the two types of tasks (central CNV preceding the motor tasks; frontal CNV preceding the cognitive tasks). The topographic effects are evidence that the two types of preparation are separate psychological constructs and imply that the neural circuitry subserving these two preparatory processes differ.

Eliminating the response requirement is a standard approach to differentiate motor and cognitive preparation; however, it has two unfortunate limitations. First, it is difficult to monitor performance when people are not responding. Our means of addressing this drawback was to ask people to complete a recognition memory test to verify that participants performed the task according to the instructions. Second, eliminating the motor response does not guarantee that participants are not engaging in some type of covert movement (e.g. subvocalization), despite strong instructions to avoid such action. Unfortunately, this problem cannot be completely solved because it is not practical to monitor the activity of every

muscle in the body (cf. van Boxtel and Brunia, 1994). Nevertheless, the results from the present experiment were highly similar to the topographic differences observed in the investigation by Damen and Brunia (1987), which found central-parietal negativities accompanying motor preparation and frontal negativities in anticipation of feedback. Similar conclusions were reported in other studies that have eliminated the motor response (Cohen and Walter, 1966; Donchin et al., 1972; Tecce, 1972; Simmons et al., 1979; Klorman and Ryan, 1980; Ruchkin et al., 1986; Tecce and Cattanach, 1993), delayed the motor response (e.g. Ruchkin et al., 1995), or isolated an additional source of activity related to information processing (e.g. Böcker et al., 1994). Together, these different approaches have produced a growing body of evidence that suggests that cognitive preparation (reflected in portions of CNV) is a psychological process that differs from motor preparation.

The topographic ERP differences observed in this experiment also suggest that motor and cognitive preparation are subserved by different neural structures. Motoric preparation was accompanied by an excitation of motor areas, whereas preparation for a semantic task was accompanied by reduced excitation of motor areas and cortical excitation of the frontal poles. We believe that these data are important evidence for task specific preparation, because the cortical activity was localized over the brain areas that have been implicated in actually executing the tasks. Countless neuroscience experiments, beginning with the classic Penfield and Boldrey (1937) study, have demonstrated that the motor cortex is involved in muscle control and explain the ERP negativities over motor areas. In contrast, encoding verbal information involves prefrontal areas (Shallice et al., 1994; Tulving et al., 1994); therefore, the increased excitability over the frontal lobes prior to the cognitive (i.e. memory) tasks may reflect preparation of the frontal lobes to encode verbal information.

The results from these investigations of the neural basis of cognitive and motoric preparation can be understood within the context of the neuroanatomical model of attention first described by

Skinner and Yingling (1977) that was later expanded to include motor preparation (Brunia, 1993). Both of these models posit that the thalamus, under frontal lobe control, acts as a gate to open and close communication channels to accommodate information processing needs. In a cued RT task, for example, two gates will be open during the preparation for the task: (a) a sensory gate for the particular modality in which stimuli are delivered; and (b) a motor gate to prepare the motor cortex for the execution of the response. Previously, topographic ERP differences have been regarded as evidence that the preparatory processes are implemented by different thalamo-cortical channels or different thalamic gates (e.g. Brunia, 1993), although additional evidence for the existence of task specific thalamo-cortical channels should also come from imaging techniques that have superior spatial resolution to ERP methods (e.g. intracellular recording, PET, fMRI, etc.). Regardless of the subcortical mechanisms involved in preparation, the present experiment suggests that changes in cortical activity accompany preparation for different kinds of tasks, suggesting that there may be multiple task gates. For example, a motor gate is open when the task is motoric, and a semantic gate is open when the task involves processing verbal stimuli. Future research should be directed toward identifying other types of task gates, such as a gate for spatial functions.

In addition to identifying task gates, the investigation of sensory gates (the other half of the neural model) can aid our understanding of how the brain functions when people prepare to make responses. According to those models described earlier, the visual gate should have been open in all of the tasks used in this experiment because the stimuli were presented visually. Unfortunately, we were unable to explore this hypothesis in any detail because we were not able to sample ERPs at occipital sites. Other researchers are currently exploring sensory gating in the brain (e.g. Brunia, 1993). Some interesting predictions about the function of these sensory gates come from behavioral investigations of preparation. For example, Pashler (1991) found that people can process auditory and visual information when the

delay between the stimuli is as short as 50 ms. Thus, people seem to be able to process information presented in different modalities in a parallel fashion, a finding that strongly suggests that people are able to have at least two sensory gates open at one time. These results suggest that ERP investigations of sensory gates should explore the number of gates that can be open at one time.

Although these questions await further work, the results from this experiment are clear. A recognition memory paradigm can be used to eliminate the motor response requirement and to investigate how people prepare for information processing. Preparation to respond motorically (characterized by central negativity) apparently activates a different neural network than preparation for semantic processing (characterized by an additional frontal negativity). Topographic ERP differences during preparation, like the kind reported in this article, may reflect the activation of task specific attentional networks that are under control of a neural system involving the frontal cortex, thalamus, and mesencephalic reticular formation. As more is understood about the neural basis of attention and preparation, the sorts of procedures used in this study might be used to investigate attentional deficits or intentions to perform acts (i.e. prospective memory; cf. Bisiacchi, 1996)

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