*Psychophysiology, 34* (1997), 703–711. Cambridge University Press. Printed in the USA.


# Effects of attentional and stressor manipulations on the P50 gating response

PATRICIA M. WHITE AND CINDY M. YEE
Department of Psychology, University of California, Los Angeles, USA

**Abstract**

The decline in amplitude of the P50 component of the event-related potential to the second of paired clicks has been suggested as a measure of preattentional gating. Two experiments were conducted to assess the effects of attention and a psychological stressor on P50. Experiment 1 included two choice reaction time tasks designed to direct attention selectively to the first or second click in each pair. Results suggest that the N100 component was responsive to attentional manipulations, whereas P50 was not affected. Experiment 2 examined the impact of a brief psychological stressor on the P50 response. Parallel mental arithmetic tasks were administered silently and orally. Self-report and measures of autonomic activity were used to assess the level of stress occurring during the performance of the mental arithmetic tasks. Results indicate that P50 suppression was sensitive to the acute stressor, the oral mental arithmetic task. Implications of these findings for studies of P50 suppression in schizophrenia are discussed.

**Descriptors:** P50, Sensory gating, Attention, Psychological stressor, Heart rate, Electrodermal activity

Normal filtering during information processing involves a diminished response to some stimuli and thus allows individuals to regulate vigilance by ignoring extraneous stimuli and attending to relevant stimuli. Gating, which represents a specific form of this filtering process, refers to the strength of inhibitory circuits in a conditioning–testing paradigm, in which some form of paired or sequential stimuli are presented to an individual. In a series of studies, Freedman et al. (1987) demonstrated that the P50 component of the auditory event-related potential (ERP) is reduced in response to the second or test stimulus relative to the response elicited by the initial or conditioning stimulus when the two clicks are delivered 500 ms apart, and pairs of clicks are separated by an intertrial interval (ITI) of at least 10 s. The first stimulus is believed to activate or condition the inhibition, whereas the second stimulus tests the degree of inhibition (e.g., Freedman et al., 1987; Freedman, Adler, Waldo, Pachtman, & Franks, 1983). A metric frequently used to describe the relationship between these two responses is the test/conditioning suppression ratio. In normal individuals, the typical P50 suppression ratio has been reported to be less than .40, whereas under the same conditions ratios are often substantially higher in individuals with schizophrenia (e.g., Freedman et al., 1987). This reduced or absent P50 suppression in schizophrenic patients is hypothesized to reflect neuronal impairment of auditory sensory gating and preattentive processes (Freedman et al., 1987; Freedman, Waldo, Bickford-Wimer, & Nagomoto, 1991).

Although sensory gating is theoretically inferred from alterations to the amplitude of the P50 response to the test stimulus (e.g., Freedman et al., 1987), the precise relationship between conditioning and test responses has yet to be clearly specified (Smith, Boutros, & Schwarzkopf, 1994). Previous research on gating, for instance, has found P50 to the conditioning stimulus to be significantly reduced among unmedicated schizophrenic patients (e.g., Adler et al., 1982; Freedman et al., 1983) and undifferentiated/disorganized schizophrenic patients (e.g., Boutros, Zouridakis, & Overall, 1991) in comparison with normal comparison participants. Moreover, Boutros et al. (1991) found no differences between schizophrenic and normal control participants in the P50 amplitude response to the testing stimulus. Given this pattern of findings in schizophrenic patients and reliance on the ratio measure of P50 suppression, it is important to determine the extent to which transient variables, such as stress and anxiety, or more stable factors, such as psychopathology, influence the conditioning and test responses differentially.

For gating to be inferred accurately, changes in P50 also must result from inhibition rather than from fluctuating attention or incomplete neuronal recovery (e.g., Jerger, Biggins, & Fein, 1992). That is, the demonstration of P50 as a preattentive component is a necessary antecedent condition if the P50 suppression ratio is to represent the hypothesized measure of gating. Toward that end,

This article is based on a thesis submitted by Patricia M. White in partial fulfillment of the requirements for the master's degree in psychology at the University of California, Los Angeles, under the direction of Cindy M. Yee. Portions of this research were presented at the annual meeting of the Society for Psychophysiological Research, Toronto, Canada, 1995. The re search was supported in part by the Committee on Research of the Academic Senate of the Los Angeles Division of the University of California, and by a predoctoral fellowship from the National Institute of Mental Health (MH14584).

We thank Keith Nuechterlein for serving as a member of the thesis committee and William Troyer for technical and software assistance.

Address reprint requests to: Cindy M. Yee-Bradbury, Department of Psychology, University of California, Los Angeles, 405 Hilgard Avenue, Los Angeles, CA 90095-1563, USA. E-mail: yee@psych.ucla.edu.

Hillyard, Hink, Schwent, and Picton (1973) found P50 amplitude to be relatively unaltered by changes in attention using trains of single stimuli presented with irregular interstimulus intervals. Jerger et al. (1992) similarly concluded that P50 is immune to the effects of attention when they demonstrated, with paired click stimuli, that P50 amplitude to the test stimulus fails to change in response to attentional manipulations that alter the N100 component of the ERP. In their paradigm, attention to the test stimuli was manipulated by instructing participants to discriminate either the number or sound intensity among four click stimuli. Another investigation, however, reported contradictory results. Using four manipulations of experimental demand, Guterman, Josiassen, and Bashore (1992) found that P50 amplitude to the testing stimulus was influenced significantly when participants selectively counted paired stimuli.

Studies examining the influence of other psychological factors known to influence measures of information processing also have yielded inconclusive results. Waldo and Freedman (1986) instructed participants to perform a silent mental arithmetic task while listening to paired clicks. They found that the mental arithmetic task significantly reduced N100 amplitude but did not alter the P50 suppression ratio. There was some suggestion, however, that increased anxiety might be associated with reductions in P50 suppression in a small portion of their sample. Using a cold-pressor manipulation, Johnson and Adler (1993) successfully disrupted P50 suppression in a group of normal control participants, although the degree of impairment varied considerably between participants.

Taken together, results of these studies provide somewhat conflicting evidence as to the involvement of psychological variables on P50. The present study was undertaken to reconcile differences among these studies and to investigate the extent to which psychological processes might influence P50 suppression. Specifically, separate experiments were conducted to examine the effects of attention and a brief psychological stressor on P50 amplitude suppression.

## EXPERIMENT 1: THE EFFECTS OF ATTENTION

Experiment 1 was designed to clarify the role of attention in P50 suppression by examining methodological differences that might account for the contradictory results reported by Jerger et al. (1992) and Guterman et al. (1992). Building on the paradigm developed by Jerger et al., several stimulus parameters were modified to reconcile differences between the two studies. The duration of click stimuli was increased to determine whether a more salient stimulus might foster attentional influence on the P50 response. Instead of the 0.05-ms square-wave click reported by Jerger et al., a longer click duration was introduced to more closely approximate the 10-ms click used by Guterman et al. The duration of the varying ITI was increased to allow for more complete neuronal recovery. In comparing the effects of various ITIs on P50, Zouridakis and Boutros (1992) concluded that durations shorter than 8 s do not permit the inhibitory mechanism of the brain to fully recover between trials. Jerger et al. used a 7–8 s varying ITI, whereas Guterman et al. (1992) relied on a fixed ITI of 11 s. Although a varying ITI was used in the present study, the minimum duration was set at 10 s. In addition, two procedural changes were implemented. First, the traditional passive P50 protocol was included to serve as a baseline for direct comparison with the other experimental tasks. Second, electroencephalogram (EEG) data were corrected for the effects of ocular noise. Jerger et al. excluded all trials containing significant eye movement activity, whereas Guterman et al. employed an eye movement correction procedure. Thus, this experiment attempted to reconcile several differences between the protocols used in the studies reported by Jerger et al. and Guterman et al. The focus of this investigation was to test whether the P50 suppression ratio is preattentive in time course and therefore is an adequate measure of sensory gating. To verify that attention had been engaged, this protocol relied on N100 amplitude changes (Hillyard et al., 1973).

### Method

#### *Participants*

Six men and seven women between 18 and 35 years of age participated in this study. Two of the participants were graduate student volunteers, and the rest were undergraduate students who received course credit for their participation. Participants who reported a personal or family history of neurological or psychiatric disorders or a personal history of drug or alcohol abuse were not included in the study. Individuals who smoked regularly or during the 48 hr prior to testing were also not included because nicotine has been found to have a transient effect on P50 sensory gating (Adler, Hoffer, Griffith, Waldo, & Freedman, 1992). All participants received audiometric testing to verify normal hearing and all provided informed consent.

#### *Psychophysiological Recording Methods and Apparatus*

EEG was recorded from three midline electrode sites, Fz, Cz, and Pz (Jasper, 1958), referenced to linked electrodes placed on the participant's ear lobes. The electrooculogram (EOG) was recorded by placing electrodes above and below the right eye. All of these measures were recorded from Sensormedics miniature Ag/AgCl electrodes, and all impedances for recording electrodes were below 5,000 Ω. Signals were collected with a Grass Model 12 Neurodata Acquisition System with half-amplitude analog filters at 0.1 and 1000 Hz. EEG signals were amplified 20,000 times; EOG was amplified 5,000 times. Stimulus presentation and data collection were controlled with an ASYST program using a Keithley Metrabyte DAS1602 laboratory data acquisition board on a 66-MHz Dell 80486 DX-based personal computer. Data were sampled for 1,200 ms at 1000 Hz within each channel, beginning 200 ms before stimulus presentation. Reaction time (RT) was recorded from a button press with the thumb of the dominant hand and was measured in milliseconds from the conditioning stimulus. RT data collected for two participants were unavailable due to equipment malfunction.

#### *Auditory Stimulation*

Click stimuli and background noise were created by amplification of white noise generated by a San Diego Instruments Sound Generator board. Duration and intensity of the click stimuli were controlled by a DAS 1602 D/A board. The white noise was amplified further through a Coulbourn Instruments Audio Mixer-Amplifier and was delivered to each participant over Realistic Nova 28 headphones (Tandy Corporation, Houston, TX). Sound levels of the stimuli were verified by a Davis Instruments SL-130 sound level meter read from the A scale.

High-intensity clicks were delivered at 90-dB SPL with 40-dB SPL background white noise. Moderate-intensity clicks were 80-dB SPL with 40-dB SPL background white noise. All clicks were 3 ms in duration, and all paired clicks were separated by an interclick onset interval of 500 ms. The time between onset of the first stimulus in successive pairs (ITI) varied between 10 and 14 s.

### *Procedure*

Participants were presented with three tasks while seated upright in a sound-attenuated room. During the baseline task, participants were instructed to sit quietly and listen to 80 trials of high-intensity paired clicks, with a 30-s rest period after Trial 40. During the two selective attention tasks, four types of stimuli were presented in random order: (a) moderate-intensity single clicks, (b) moderate-intensity paired clicks, (c) high-intensity single clicks, and (d) high-intensity paired clicks. Fifty-two percent of the trials (82 trials) included high-intensity paired clicks identical to the clicks administered during the baseline task. Each of the three remaining types of clicks accounted for 16% (26 trials) of the total trials per task administration. Thus, a total of 160 trials was presented during each of the selective attention tasks.

For the intensity task, participants were instructed to press the response button as soon as a high-intensity stimulus was detected, regardless of whether the stimulus involved single or paired clicks. This discrimination could be made on the basis of information present in the first click. For the number task, participants were directed to press the response button as soon as they could detect a pair of click stimuli, regardless of whether the clicks were of moderate or high intensity. For this task, the presence or absence of a second click was necessary for correct task performance.

Identical auditory stimuli were administered during both tasks; only the instructions were varied. All participants received both selective attention tasks, with the order of administration counterbalanced across participants. Participants received a 3-min break between the baseline and first selective attention task and a 5-min break between the two selective attention tasks.

### *Waveform and Component Analysis*

Single trials were individually screened by computer algorithm before being included in the averages. Single EEG trials were excluded from the average if EEG at any electrode site saturated the A/D converter ($>\pm 256$ $\mu$V). Those single trials remaining after this preliminary screening were corrected for the effect of eye movement by using a procedure that removes ocular noise (Gratton, Coles, & Donchin, 1983; Miller, Gratton, & Yee, 1988). After correction for eye movement, trials for which a participant provided an incorrect response were excluded. Single trials were Fourier filtered at 10–50 Hz for measurement of the P30 and P50 components and at 1–20 Hz for measurement of N100 (Jerger et al., 1992). For each participant, at least 65 trials were included in the ERP averages computed for the high-intensity paired clicks in each of the baseline and selective attention tasks following this process.

All ERP components were measured at Cz. For measurement of amplitude, the P50 peak was determined relative to the preceding negativity (Jerger et al., 1992).[1] The latency of the P50 peak was identified as the maximum positivity between 40 and 80 ms poststimulus. P30 amplitude and latency were identified at the most positive point between 20 and 40 ms. The maximum negativity between the P30 latency and the P50 latency was then used for measuring P50 amplitude. N100 amplitude was identified as the most negative point in the 50–150-ms poststimulus window and was measured relative to a 200-ms prestimulus baseline established before the pair of clicks.

### *Data Analysis*

Repeated measures analyses of variance (ANOVAs) were conducted on the P50 and N100 amplitude data using two within-subject fully crossed factors: task (passive vs. intensity vs. number) and click (test vs. conditioning). In addition, the more traditional suppression ratio (test/conditioning) for the P50 component was subjected to a single-factor ANOVA with one within-subject factor, task. RT also underwent single-factor ANOVA with one within-subject factor, task. P50 and N100 latencies also were measured and analyzed in the present study. Due to the length of this report, however, the latency data will not be discussed. Greenhouse–Geisser corrected $p$ values were used throughout (Geisser & Greenhouse, 1958). Post hoc analyses were performed using the Newman–Keuls statistic at a 95% level of confidence.

## Results

### *Reaction Time*

Mean RT data indicated that participants appropriately directed attention to the initial or conditioning stimulus during the intensity task with an average response of 502.2 ms ($SD$ = 102.4). The average RT response to the second or test stimulus during the number task was 267.4 ms ($SD$ = 62.7). RT differences between the two experimental conditions may reflect greater task difficulty associated with the intensity discrimination or may be due to the variable versus fixed ITI preceding the conditioning and test stimuli, respectively.

### *N100*

Figure 1 presents grand-average ERP waveforms. N100 amplitude showed both click, $F(1,12) = 13.85$, $p < .01$, and Task × Click,

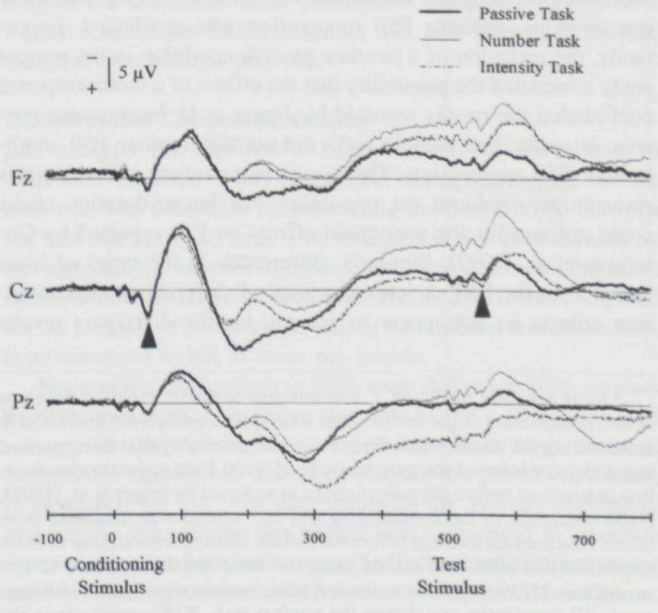


**Figure 1.** Grand average event-related potential (ERP) waveforms for the passive baseline and each attentional manipulation at the three midline sites in Experiment 1. The P50 component is indicated with arrowheads at the Cz lead.

[1]Because P50 is small and often occurs as the N100 begins, the measurement of the P50 component relative to the prestimulus baseline may introduce a possible artifact. Specifically, the overlap between P50 and N100 can cause the entire P50 to be negative (Erwin & Buchwald, 1986). Therefore, selective digital filtering of the P50 and N100 components, and measurement of P50 relative to preceding negativity, as recommended by Jerger et al. (1992) and described above, was applied to reduce the potential effects of this artifact.

$F(2,24) = 29.64, p < .001, \epsilon = 0.8814$, effects. Figure 2 illustrates this interaction effect. Post hoc comparisons revealed that, whereas N100 amplitude to the test stimulus was smaller than that to the conditioning stimulus during the passive and the intensity tasks, there was no difference in the N100 amplitude to the two clicks during the number task. These results follow the predicted pattern for the N100 component of diminished response to the test stimulus in the traditional passive P50 task and in the intensity task when attention is directed to the first click but an enhanced response to the test stimulus when attention is directed toward the second click during the number task. Similar to findings by Jerger et al. (1992), N100 amplitude to the conditioning stimulus did not differ across tasks, suggesting that participants' attention was equally engaged across conditions.[2]

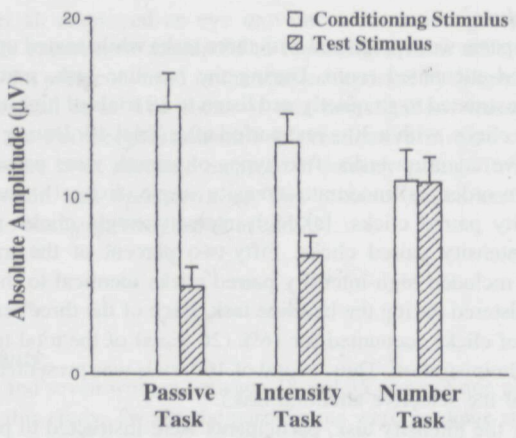


**Figure 2.** Effects of the attentional manipulation on N100 amplitude for the conditioning stimulus and test stimulus in Experiment 1.

### *P50*

Figure 3 depicts the click effect for P50 amplitude, $F(1,12) = 29.54, p < .001$. Task and Task × Click effects did not approach significance, $F(2,24) = 1.97$ and $F(2,24) = 1.12$, respectively. Post hoc analysis revealed that P50 amplitude to the test stimulus was suppressed compared with the response to the conditioning stimulus. The lack of a Task × Click interaction is consistent with the view that P50 gating is not influenced by attentional manipulations.

### *P50 Suppression Ratio*

The P50 amplitude ratio (test/conditioning) also demonstrated no significant effect for task, $F(2,24) = 1.76$ (passive task, .39; intensity task, .42; number task, .49).

### Discussion

Results of this study replicate and extend the findings of Jerger et al. (1992) in showing that P50 suppression is not affected by certain attentional manipulations that influence later ERP components. N100 amplitude and the RT data clearly demonstrated the success of the intended attentional manipulation on the second or test stimulus, whereas P50 suppression was unaffected. Importantly, the inclusion of a baseline passive condition in the present study eliminated the possibility that the effects of a motor response confounded the results reported by Jerger et al. because our passive, intensity, and number tasks did not differentiate P50 amplitude or P50 suppression. The use of more salient stimuli in this research also reduced the possibility that longer-duration clicks could account for the attentional effects on P50 reported by Guterman et al. (1992). Similarly, differences in the types of trials included in the ERP averages because of different artifact exclusion criteria do not appear to account for the discrepant results obtained under the protocols of Jerger et al. and Guterman et al. Failure of neuronal recovery does not appear to be a potential confound (Boutros et al., 1991) because a pattern of results was obtained similar to those of Jerger et al. when using longer ITIs (10–14 s). Taken together, these results concur with those of Jerger et al. and lend additional support to the suggestion that P50 represents a preattentive component.

## EXPERIMENT 2: THE EFFECTS OF A PSYCHOLOGICAL STRESSOR

By establishing that P50 is not affected by attention under experimental conditions, results of Experiment 1 help to confirm the viability of P50 as typically interpreted in studies of gating. Studies of other important factors that might influence or mediate the P50 suppression system are needed, however, to determine any constraints in using P50 suppression in research on gating and perhaps to illuminate the basis for reduced or absent suppression in some psychiatric groups. Experiment 2 was designed to explore the role of psychological stress on P50 suppression. If transient stress disrupts P50 suppression, level of psychological stress would need to be monitored carefully in future studies. Two mental arithmetic

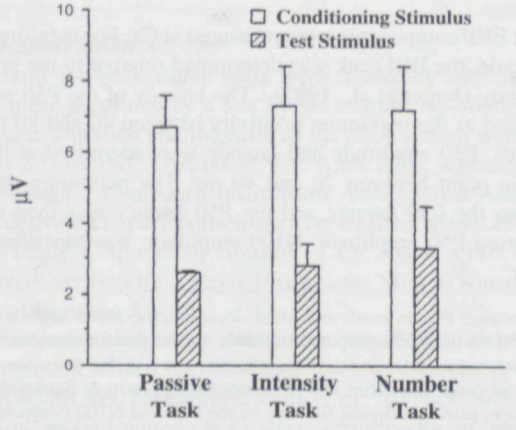


**Figure 3.** Effects of the attentional manipulation on P50 amplitude for the conditioning stimulus and test stimulus in Experiment 1.

[2]As is apparent in Figure 1, a contingent negative variation develops before presentation of the test stimulus when participants were instructed to count during the number task. To examine the possibility that this sustained negativity confounded the measurement of N100 from a prestimulus baseline determined before the pair of clicks as reported by Jerger et al. (1992), N100 amplitude to the conditioning and test stimuli was measured from 80-ms baselines established before each click. Results were similar to those obtained when N100 was scored using the more distal baseline, with two exceptions. N100 amplitude to the test stimulus was significantly different across all three tasks and during the number task, N100 amplitude to the test stimulus was smaller than that to the conditioning stimulus. These data continue to suggest that attention was directed appropriately toward the test stimulus during the number task although the magnitude of the effect is less pronounced than that observed using the scoring procedure of Jerger et al.

tasks were constructed to maintain the same degree of difficulty across tasks while differing in level of stress or anxiety. The silent mental arithmetic task was adapted from a protocol used by Waldo and Freedman (1986) that was found to have no impact on gating and minimal effects on self-reported anxiety. We contrasted this task with a second mental arithmetic task that was performed aloud and that has been shown to be an acute psychological stressor that increases norepinephrine and epinephrine activity comparably in individuals who are usually high or low in cardiovascular reactivity (Sgoutas-Emch et al., 1994). We predicted that the oral mental arithmetic task would disrupt P50 suppression because norepinephrine has been shown to play a role in gating (Adler et al., 1994; Johnson & Adler, 1993; Stevens, Meltzer, & Rose, 1993). Relative to activity elicited during the passive task, attenuation of N100 was expected to reflect interference from the performance of mental arithmetic and to verify that the manipulation was sufficiently engaging of attention. Measures of heart rate (HR), electrodermal activity (EDA), and self-report were included as converging measures of stress and anxiety.

## Method

### *Participants*

Participants were the same 13 from Experiment 1. All data were in the same session as Experiment 1.

### *Psychophysiological Recording*

Recordings of EEG and EOG were as described in Experiment 1. HR was recorded using two standard electrodes placed bilaterally on the lower ribs. The electrocardiogram signal was passed through a Grass Model 12 amplifier to a Coulbourn Dual Comparator/Window Discriminator that acted as a Schmitt trigger. The trigger level was adjusted to trigger reliably for each participant's R-wave. The latency of the rising edge of the signal output by the Coulbourn apparatus was recorded to the nearest millisecond.

EDA was recorded from a pair of standard 1.5-cm Sensormedics Ag/AgCl electrodes (0.5-cm recording surface) attached to the volar surface of the second and third finger of the nondominant hand. The electrolyte was sodium chloride in Unibase (Fowles et al., 1981). EDA was recorded directly by applying a constant 0.5 V across the electrode pair using a Coulbourn S71-22 SC Coupler set for DC coupling. EDA level was digitized at 20 Hz for 3 s before and 6 s after each auditory stimulus onset. Resting levels of HR from one participant and EDA from three participants were unavailable due to technical difficulties.

### *Auditory Stimulation*

Click stimuli and background noise were as described in Experiment 1. The two mental arithmetic tasks were completed while listening to 80 trials of paired clicks that were identical to those presented during the passive baseline task in Experiment 1.

### *Procedure*

To assess resting levels of autonomic activity, HR and EDA were recorded continuously over a 3-min resting baseline period. After obtaining a resting baseline, the experimental conditions were introduced.

Participants were instructed to perform two mental arithmetic tasks that were separated by a 5-min break. Each task consisted of seven 2-min serial subtraction problems of varying difficulty. Participants performed each task without stopping and were prompted to speed their responses during four predetermined trials in each test administration (Click Trials 8, 26, 52, and 69).

During the first task, participants were asked to perform all serial subtractions aloud and were told that mistakes would be corrected by the experimenter. They were informed that auditory clicks would be presented during the subtraction tasks and that the clicks might make the mental arithmetic more challenging. A 1-min break occurred approximately 7 min after the start of the task. The subtractions used during the oral mental arithmetic (oral MA) task were as follows: Subtraction 1: 3,605 by 3s, Subtraction 2: 5,428 by 7s, Subtraction 3: 6,507 by 13s, Subtraction 4: 8,203 by 8s, Subtraction 5: 7,417 by 14s, Subtraction 6: 9,232 by 17s, and Subtraction 7: 9,545 by 19s.

During the second task, participants were instructed to perform the subtractions silently and without facial movement. They were again informed that auditory clicks would be presented during the subtraction tasks and that the clicks might make the mental arithmetic more challenging. Participants were informed that the experimenter might probe for a correct response at any time and that any incorrect answers would be corrected by the experimenter. Participants were prompted for a subtraction response and asked to speed up their performance during the same four click trials, during which the speed instructions were given during the oral MA task. Participants were also prompted during the 1-min break at the halfway point and at the end of the task. Thus, a total of six subtraction responses was elicited during the task. The subtractions used during the silent mental arithmetic (silent MA) task were as follows: Subtraction 1: 2,907 by 3s, Subtraction 2: 6,828 by 7s, Subtraction 3: 9, 561 by 13s, Subtraction 4: 5,113 by 8s, Subtraction 5: 8,318 by 14s, Subtraction 6: 9,994 by 17s, and Subtraction 7: 8,442 by 19s.

The oral MA task was always run first. Counterbalancing was not used because prior experience with the silent MA task could decrease the level of stress and anxiety associated with performance of the oral MA task.

Prior to the administration of either arithmetic task, participants provided ratings on a 7-point scale of how difficult they perceived arithmetic problems to be in general, how much they liked arithmetic, and how anxious they felt at this point in the testing. After each of the arithmetic tasks, participants completed ratings on a 7-point scale of how difficult the task was, how interesting the task was, and how anxious they felt.

### *Waveform and Component Analysis*

ERP analysis was identical to Experiment 1. No fewer than 76 trials were included in any of the ERP averages. Average HR for each trial was calculated by subtracting the time (in ms) between the first and last heart beat. This time period was then divided by one less than the number of recorded beats to determine the mean interbeat interval (IBI) for each trial. The mean IBI was computed for the 80 trials of paired clicks during each mental arithmetic task, then converted to HR in beats per minute.

Nonspecific fluctuations in EDA were defined as 0.05-$\mu$s rises in EDA level with a minimum rise time of 0.5 s. The number of nonspecific fluctuations was computed for each trial. Summed nonspecific fluctuations was calculated for the paired click trials, as described for HR. For data analyses, the average number of nonspecific fluctuations per minute was calculated to permit a direct comparison between nonspecific fluctuations obtained during the 3-min resting baseline and 16-min mental arithmetic conditions.

### *Data Analysis*

As described by Sgoutas-Emch et al. (1994), two measures of task performance were calculated for the oral MA task: number of

subtractions attempted (including errors) and percent correct. To evaluate performance on the silent MA task, the total subtractions attempted were approximated by adding the number of subtractions necessary to reach the reported result at each of the six probes. The percentage correct of these six responses also was calculated.

For P50 analyses, the passive baseline task obtained during Experiment 1 was included in a set of repeated-measures ANOVAs with two within-subject fully crossed factors: task (passive vs. oral MA vs. silent MA) and click (testing vs. conditioning). In addition, the suppression ratio (test/conditioning) for each component was subjected to a single-factor ANOVA with one within-subject factor. The 7-point anxiety measures also underwent single-factor ANOVAs with one within-subject factor, task. Greenhouse–Geisser corrected $p$ values were used throughout. Post hoc analyses were performed using the Newman–Keuls statistic at a 95% level of confidence unless otherwise indicated.

We performed planned comparisons with the HR and EDA measures to verify the efficacy of the oral MA task as a brief but acute psychological stressor and to determine whether our effect replicated that of Sgoutas-Emch et al. (1994). Accordingly, autonomic responses to the oral MA task were compared with responses elicited during the resting baseline. Planned comparisons also were undertaken between the silent and oral MA tasks to verify larger increases in autonomic activity when the task was performed aloud.

## Results

### *Performance*

Participants attempted a greater number of subtractions during the oral MA task ($M = 157.5$, $SD = 26.5$) than during the silent MA task ($M = 63.7$, $SD = 11.5$), $F(1,12) = 147.29$, $p < .001$. The percentage of correct responses also varied significantly by task, $F(1,12) = 49.09$, $p < .001$, with participants performing accurately on 87% and 35% of subtractions attempted during oral and silent MA tasks, respectively. Both measures of performance during the silent MA task are likely to be artificially suppressed, however, because they are based on responses provided during the six probe points rather than on ongoing, continuous serial subtractions. A more valid comparison is offered by contrasting the number of subtractions attempted during the last series of subtractions performed for each task. With this measure, no significant difference in performance was measured, $F(1,12) = 0.60$.

### *Self-Report*

The 7-point anxiety rating showed an effect for task, $F(2,24) = 6.61$, $p < .01$, $\epsilon = 0.8562$. Post hoc comparisons demonstrated that anxiety was higher after oral MA ($M = 4.3$, $SD = 1.1$) than before oral MA ($M = 3.0$, $SD = 1.2$). Anxiety levels measured after silent MA ($M = 3.6$, $SD = 1.2$) did not differ significantly from either of the two previous ratings. These results suggest that the oral MA task successfully manipulated anxiety but that anxiety level was not perceived to return completely to prestressor levels after silent MA. The 7-point task difficulty rating did not discriminate between tasks ($M = 5.4$ for both), $F(1,12) = 0.03$, suggesting that the two arithmetic tasks were perceived to be equally challenging.

### *N100*

Grand-average waveforms are presented in Figure 4. N100 amplitude produced task, $F(2,24) = 29.45$, $p < .001$, $\epsilon = 0.6183$, click, $F(1,12) = 33.00$, $p < .001$, and Task × Click, $F(2,24) = 33.24$, $p < .001$, $\epsilon = 0.6128$, effects (see Figure 5). Post hoc comparisons revealed that, whereas N100 to the test stimulus was smaller than to the conditioning stimulus during the passive and silent MA tasks, no difference was measured for the two clicks during the oral MA task. The undifferentiated response to the two clicks during oral MA appears to have been due to the attenuation of N100 amplitude to the conditioning stimulus. Post hoc comparisons also confirmed that N100 decreased as a function of task for the conditioning response only, indicating that the oral MA task disrupted attention more than did the silent MA task. As expected, the arithmetic tasks did not significantly influence N100 amplitude to the test stimulus, where directed attention is assumed to be minimal.

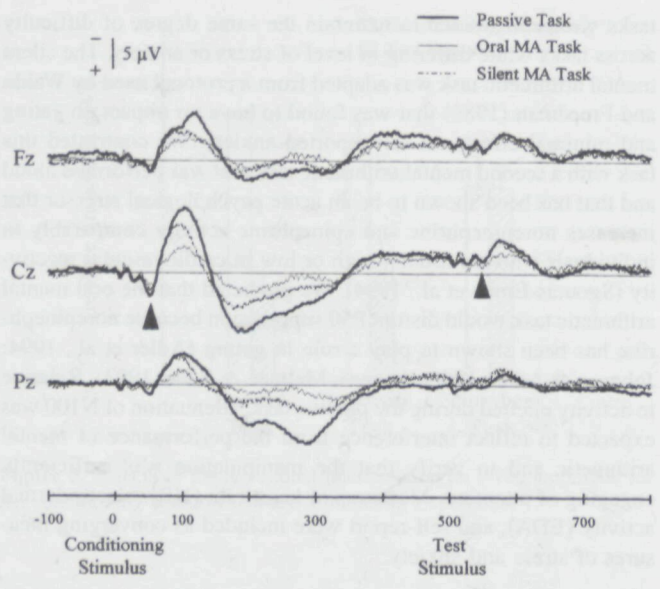


**Figure 4.** Grand average event-related potential (ERP) waveforms for the passive baseline and each mental arithmetic task at the three midline sites in Experiment 2. The P50 component is indicated with arrowheads at the Cz lead.

### *P50*

P50 amplitude showed click, $F(1,12) = 38.19$, $p < .001$, task, $F(2,24) = 19.16$, $p < .001$, $\epsilon = 0.7288$, and Task × Click,

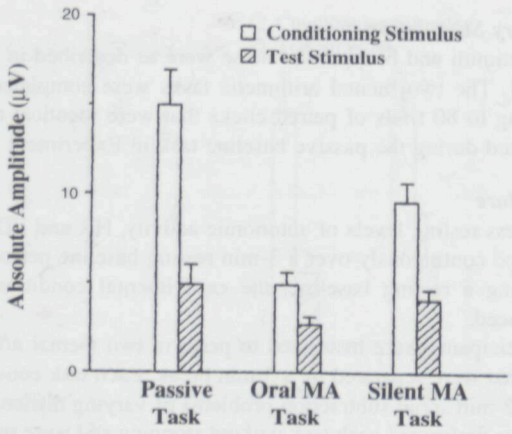


**Figure 5.** Effects of the psychological stressor manipulation on N100 amplitude for the conditioning stimulus and test stimulus in Experiment 2.

$F(2,24) = 10.91, p < .001, \epsilon = 0.8879$, effects. Figure 6 illustrates the impact of the stressor manipulation on P50 to the two clicks. As with N100 amplitude, post hoc comparisons revealed that, whereas P50 amplitude to the test stimulus was smaller than to the conditioning stimulus during the passive and silent MA tasks, P50 to the two clicks was comparable during the oral MA task. Post hoc comparisons also determined that the task effect was significant for the conditioning stimulus but not for the test stimulus. In contrast to results obtained for N100, P50 to the conditioning stimulus was smaller during the oral MA task than during the other two tasks but did not differ between the passive and silent MA tasks. The lack of a differentiated P50 response to the silent MA and passive tasks suggests that, unlike N100, mere inclusion of a competing task was insufficient to disrupt P50. Instead, P50 appears to have been sensitive only to the stress and anxiety or disruption of attention associated with the oral MA task.

### *P50 Suppression Ratio*

P50 amplitude ratio (test/conditioning) showed a main effect for task, $F(2,24) = 5.19, p < .05, \epsilon = 0.6187$. Post hoc comparisons indicated that gating was significantly reduced in the oral MA task. In the traditional passive task, the P50 response produced a ratio ($M = 0.39$, $SD = 0.22$) within the range considered normal by Freedman et al. (1983, 1987). Examination of the mean ratio scores during the oral MA task revealed that suppression surpassed the normal range ($M = 0.68$, $SD = 0.39$), whereas suppression during the silent MA task was within normal limits ($M = 0.35$, $SD = 0.16$).

### *Heart Rate*

Consistent with results obtained by Sgoutas-Emch et al. (1994), the oral MA task produced higher mean HR than did the resting baseline, $t(11) = 3.25, p < .01$, and silent MA task, $t(11) = 5.50, p < .001$. These data are presented in Table 1.

### *Electrodermal Activity*

An analysis of the average number of nonspecific fluctuations per minute (Table 1) showed significant task effects whereby the oral MA task elicited a greater number of nonspecific fluctuations than did the resting baseline, $t(9) = 2.57, p < .05$, and silent MA task, $t(9) = 3.0, p < .05$. Mean number of nonspecific fluctuations obtained over the 16-min duration of the oral and silent MA tasks was 39.5 and 14.9, respectively. Significant task effects for HR and number of nonspecific fluctuations provides converging evidence that autonomic arousal was heightened during the oral MA task relative to the silent MA task.[3]

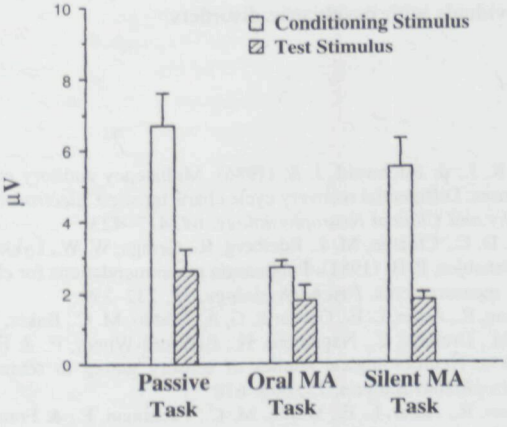


**Figure 6.** Effects of the psychological stressor manipulation on P50 amplitude for the conditioning stimulus and test stimulus in Experiment 2.

**Table 1.** *Mean Values and Standard Deviations for Autonomic Variables to High-Intensity Clicks in Experiment 2*

| | Resting baseline | | Oral MA task | | Silent MA task | |
|---|---|---|---|---|---|---|
| Variable | *M* | *SD* | *M* | *SD* | *M* | *SD* |
| HR | 66.25 | 10.66 | 76.17 | 13.00 | 69.17 | 9.98 |
| NSFs/min | 0.57 | 0.52 | 2.47 | 2.23 | 0.93 | 0.90 |

*Note:* HR = heart rate; NSFs/min = nonspecific fluctuations per minute. $n = 12$ for HR measure and $n = 10$ for EDA measure.

## Discussion

Results of Experiment 2 suggest that the impact of stress and anxiety on P50 amplitude and the P50 suppression ratio can be considerable depending on the psychological stressor. Similar to previous research using a cold-pressor manipulation (Johnson & Adler, 1993), the oral MA task suppressed the initial P50 response and yielded an elevated test/conditioning ratio that exceeded 65%. P50 suppression ratios obtained during the passive and silent MA tasks, in contrast, fell within the range considered normal by Freedman et al. (1987). The pattern of results for the silent MA task closely parallels those reported by Waldo and Freedman (1986) for silent subtraction. Specifically, the concurrent performance of silent MA increased the P50 suppression ratio somewhat, although the change from the traditional passive task was not statistically reliable in either study. Thus, in the present study, performance of silent MA does not appear to constitute a psychological stressor capable of influencing P50 suppression.

The oral MA task, in comparison, had a considerable impact not only on P50 but on autonomic measures. Accompanying participants' self-report of heightened anxiety, significant increases in HR and electrodermal nonspecific fluctuations were observed during oral reports of arithmetic problems. On the basis of research conducted by Sgoutas-Emch et al. (1994), it is possible that epinephrine and norepinephrine levels would also have been found to increase substantially, had they been measured. Thus, the pattern of results obtained using an acute psychological stressor are generally consistent with those acquired during a cold-pressor test, which has also been shown to greatly increase autonomic and catecholamine activity (Ward et al., 1983).

The means by which alterations in P50 suppression ratio were accomplished, however, differed considerably between the present study and the work by Johnson and Adler (1993). In the present study, changes in P50 ratio resulted from attenuation of the P50 amplitude response to the conditioning stimulus. In the study by Johnson and Adler (1993), impairment of P50 gating was primarily a result of augmentation of P50 amplitude to the test stimulus during the cold-pressor test. As noted earlier, sensory gating is

[3]Data were collected on a separate sample of 10 participants to determine whether differences in autonomic activity, obtained between the oral and silent MA tasks, might reflect habituation effects. Counterbalancing of the two experimental manipulations produced the same pattern of results, with significant increases in HR and number of electrodermal nonspecific fluctuations exhibited during the oral MA task versus the silent MA condition.

typically inferred from alterations in P50 amplitude to the test stimulus. Our results are nonetheless informative because previous research has found P50 amplitude to the conditioning stimulus to be significantly reduced among individuals diagnosed with schizophrenia (e.g., Adler et al., 1982; Boutros et al., 1991; Freedman et al., 1983) as compared with normal participants. This study, therefore, demonstrates that P50 suppression can be modified experimentally to mimic aspects of the gating deficit associated with schizophrenia.

The basis for the apparent disruption of P50 is unclear, although several possibilities exist and highlight potential directions for future research. Although self-report and psychophysiological measures suggest that stress and anxiety were heightened when participants engaged in the oral MA task, other factors could possibly account for the diminished P50 response to the conditioning stimulus. One potential explanation is that the oral MA task drew attention away from the auditory clicks as participants focused on subtracting numbers. Such an interpretation is unlikely, however, because the silent MA task placed similar demands on participants and even served to improve slightly the P50 suppression ratio.

Another possibility is that the additional requirement to vocalize answers during the oral MA task placed a greater attentional load on participants than did the silent MA task, and the effects on autonomic activity were due to increased motor output. The current pattern of results also suggests that speech may have had a specific impact on the determinants of P50 amplitude to the conditioning stimulus. It is possible that the sound of their own voices disrupted participants' P50. During the oral MA task, participants vocalized their responses at a steady, near continuous rate. The competing auditory stimulation from hearing their own voices, therefore, may have interfered with processing of the first auditory click. Alternatively, muscle artifact has been suggested as a potential confound in studies of P50 (e.g., Griffith, Hoffer, Adler, Zerbe, & Freedman, 1995). It is conceivable that the motor activity necessary for generating speech may have disrupted P50 amplitude to the conditioning stimulus or its measurement. Although each of these possibilities will need to be pursued with additional research, their likelihood is reduced by the fact that only P50 amplitude responses to the conditioning stimulus were influenced, whereas those to the test stimulus were unaffected.

## CONCLUSION

This pair of studies was undertaken to examine factors that might influence P50 suppression and to determine the extent to which changes in P50 reflect the effects of psychological processes. The attentional manipulations and methodological enhancements of Experiment 1 confirmed and extended the finding by Jerger et al. (1992) that N100 is profoundly influenced by attention, whereas neither P50 amplitude nor its suppression are affected. Experiment 2 examined the effects of stress on P50 by introducing two mental arithmetic tasks and found substantial alterations in P50 amplitude and its suppression. Thus, although P50 suppression appears to reflect a preattentive process, it may be subject to modification by psychological states such as brief psychological stress.

The present findings have important implications for P50 studies of sensorimotor gating in schizophrenia. For instance, the effects of attention appear to be highly circumscribed (cf. Guterman et al., 1992). Regardless of whether attention was directed toward the auditory intensity of the conditioning stimulus or the occurrence of another stimulus immediately following the conditioning stimulus, no alterations to P50 amplitude or its suppression were observed. Attention, moreover, appears to have been diverted somewhat during performance of the concurrent silent MA task, but any impact on the P50 measures was not detected.

Results of Experiment 1 concur with those of Jerger et al. (1992) but contrast with those of Guterman et al. (1992). One explanation for these disparate results is that the experimental manipulation used by Guterman et al. may have affected not only attention but other mental processes. Guterman et al. required participants to discriminate a designated test stimulus in the count/no-count and go/no-go conditions. The count/no-count condition also involved maintaining a mental count of the number of designated test stimuli presented, whereas the go/no-go condition required making an RT response whenever a designated test stimulus was presented. Only the count/no-count condition was found to have a statistically significant effect on P50 amplitude suppression. Therefore, it would appear that disruption of P50 suppression was accomplished by requiring participants to perform simple arithmetic and maintain a running memory count of designated test stimuli. Although it is unclear what mechanisms can account for this disruptive effect on P50, stress and anxiety are clearly possibilities.

As suggested by the results of Experiment 2, stress can affect P50 suppression, and the impact may be more extensive than previously believed (e.g., Waldo & Freedman, 1986). Future research on sensorimotor gating, therefore, should consider monitoring levels of stress and anxiety to determine whether failures to suppress P50 result from the participants' responses to the testing situation or to some underlying pathophysiology. In addition, it will be important to extend this research and determine the extent to which P50 suppression is influenced by attention and psychological stress in individuals with psychiatric disorders.

## REFERENCES


Adler, L. E., Hoffer, L. J., Griffith, J., Waldo, M. C., & Freedman, R. (1992). Normalization by nicotine of deficient auditory sensory gating in the relatives of schizophrenics. *Biological Psychiatry, 32*, 607–616.

Adler, L. E., Hoffer, L., Nagomoto, H. T., Waldo, M. C., Kisley, M. A., & Griffith, J. M. (1994). Yohimbine impairs P50 auditory sensory gating in normal subjects. *Neuropsychopharmacology, 10*, 249–257.

Adler, L. E., Pachtman, E., Franks, R. D., Pecevich, M., Waldo, M. C., & Freedman, R. (1982). Neurophysiological evidence for a defect in neuronal mechanisms involved in sensory gating in schizophrenia. *Biological Psychiatry, 17*, 638–654.

Boutros, N. N., Zouridakis, G., & Overall, J. (1991). Replication and extension of P50 findings in schizophrenia. *Clinical Electroencephalography, 22*, 40–45.

Erwin, R. J., & Buchwald, J. S. (1986). Midlatency auditory evoked responses: Differential recovery cycle characteristics. *Electroencephalography and Clinical Neurophysiology, 64*, 417–423.

Fowles, D. C., Christie, M. J., Edelberg, R., Grings, W. W., Lykken, D. T., & Venables, P. H. (1981). Publication recommendations for electrodermal measurements. *Psychophysiology, 18*, 232–239.

Freedman, R., Adler, L. E., Gerhardt, G. A., Waldo, M. C., Baker, N., Rose, G. M., Drebing, C., Nagamoto, H., Bickford-Wimer, P., & Franks, R. (1987). Neurobiological studies of sensory gating in schizophrenia. *Schizophrenia Bulletin, 13*, 669–678

Freedman, R., Adler, L. E., Waldo, M. C., Pachtman, E., & Franks, R. D. (1983). Neurophysiological evidence for a defect in the inhibitory pathways in schizophrenia: Comparison of medicated and drug-free patients. *Biological Psychiatry, 18*, 537–551.

Freedman, R., Waldo, M. C., Bickford-Wimer, P., & Nagomoto, H. (1991). Elemental neuronal dysfunctions in schizophrenia. *Schizophrenia Research*, *4*, 233–243.

Geisser, S., & Greenhouse, S. W. (1958). An extension of Box's results on the use of the F distribution in multivariate analysis. *Annals of Mathematics and Statistics*, *29*, 886–891.

Gratton, G., Coles, M. G. H., & Donchin, E. (1983). A new method for off-line removal of ocular artifacts. *Electroencephalography and Clinical Neurophysiology*, *55*, 468–484.

Griffith, J., Hoffer, L. D., Adler, L. E., Zerbe, G. O., & Freedman, R. (1995). Effects of sound intensity on a midlatency evoked response to repeated auditory stimuli in schizophrenic and normal subjects. *Psychophysiology*, *32*, 460–466.

Guterman, Y., Josiassen, R. C., & Bashore, T. R. (1992). Attentional influence on the P50 component of the auditory event-related potential. *International Journal of Psychophysiology*, *12*, 197–209.

Hillyard, S. A., Hink, R. F., Schwent, V. L., & Picton, T. W. (1973). Electrical signs of selective attention in the human brain. *Science*, *182*, 177.

Jasper, H. H. (1958). The ten-twenty electrode system of the International Federation. *Electroencephalography and Clinical Neurophysiology*, *10*, 371–375.

Jerger, K., Biggins, C., & Fein, G. (1992). P50 suppression is not affected by attentional manipulations. *Biological Psychiatry*, *31*, 365–377.

Johnson, M. R., & Adler, L. E. (1993). Transient impairment in P50 auditory sensory gating induced by a cold-pressor test. *Biological Psychiatry*, *33*, 380–387.

Miller, G. A., Gratton, G., & Yee, C. M. (1988). Generalized implementation of an eye movement correction procedure. *Psychophysiology*, *25*, 241–243.

Sgoutas-Emch, S. A., Cacioppo, J. T., Uchino, B. N., Malarkey, W., Pearl, D., Kiecolt-Glaser, J. K., & Glaser, R. (1994). The effects of an acute psychological stressor on cardiovascular, endocrine, and cellular immune response: A prospective study of individuals high and low in heart rate reactivity. *Psychophysiology*, *31*, 264–271.

Smith, D. A., Boutros, N. N., & Schwarzkopf, S. B. (1994). Reliability of P50 auditory evoked potential indices of auditory gating. *Psychophysiology*, *31*, 495–502.

Stevens, K. E., Meltzer, J., & Rose, G. M. (1993). Disruption of sensory gating by the alpha-2 selective noradrenergic antagonist yohimbine. *Biological Psychiatry*, *33*, 130–132.

Waldo, M. C., & Freedman, R. (1986). Gating of auditory evoked responses in normal college students. *Psychiatry Research*, *19*, 233–239.

Ward, M. M., Mefford, I. N., Parker, S. D., Chesney, M. A., Taylor, C. B., Keegan, D. L., & Barchas, J. D. (1983). Epinephrine and norepinephrine responses in continuously collected human plasma to a series of stressors. *Psychosomatic Medicine*, *45*, 471–486.

(RECEIVED August 6, 1996; ACCEPTED May 2, 1997)