The Effect of Background Noise on P300 to Suprathreshold Stimuli

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The effect of background noise on P300 to suprathreshold stimuli

DEAN F. SALISBURY[a,b], **MASSIMO A. DESANTIS**[a], **MARTHA E. SHENTON**[a,b], and **ROBERT W. MCCARLEY**[a,b]

[a]*Harvard Medical School, Department of Psychiatry, McLean Hospital Belmont, Massachusetts, USA*

[b]*Boston Veterans Affairs Healthcare System, Brockton, Massachusetts, USA*

Abstract

Both the amplitude and latency of P300 vary with changes in stimulus parameters. Stimuli at intensities or pitch separations near threshold evoke a smaller and later P300. P300 is also affected by extraneous stimulus parameters in tasks where stimulus frequency separation is large and stimuli are well above intensity thresholds. For example, the presence of background white noise when tones are suprathreshold and easily detectable has been reported to increase P300 latency. However, the effects of background masking noise on P300 amplitude and scalp topography have not been reported. Subjects performed an oddball task both in the presence and in the absence of background noise. Performance accuracy was unaffected by background noise. P300 showed latency increases when noise was present, but P300 peak amplitude was unaffected. P300 scalp topography was stable across both conditions. P300 latency is affected by background noise, even when performance is not, but amplitude and amplitude topography remain unaffected.

The P300 event-related potential (ERP) has been related to endogenous or cognitive operations in contrast to exogenous or sensory factors (Donchin & Coles, 1988; Sutton, Braren, Zubin, & John, 1965). P300 generally reflects the higher-order cognitive operations related to selective attention and resource allocation rather than differences in stimulus characteristics per se. However, P300 is not completely independent from stimulus parameters.

P300 is most affected by stimulus parameters at values close to sensory threshold. Hillyard and colleagues demonstrated that at near intensity threshold, P300 amplitude was linearly coupled to stimulus discriminability. As stimuli became suprathreshold, the amplitude of P300 became decoupled from intensity. P300 amplitude showed a curvilinear relation to stimulus intensity, directly related when stimuli were not easily detected, but independent when stimuli were suprathreshold (Hillyard, Squires, Bauer, & Lindsey, 1971; Sugg & Polich, 1995). P300 latency is also affected, showing decreases as stimuli become progressively suprathreshold (e.g., Adler & Adler, 1991; Salisbury et al., 1994).

Johnson (1986,1993) summarized the interrelated factors affecting P300 amplitude in his Triarchic model. The three factors were information transfer (related to stimulus parameters and inattention); subjective meaning (related to task demands and relevance); and subjective probability (related to the perceived infrequency of the target stimulus). The latter two are thought to be independent and modulated by information transfer.

The following example illustrates the examination of stimulus parameter effects in relation to the factors affecting P300. P300 is robustly small in schizophrenia (Begleiter & Porgesz,

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Address reprint requests to: D.F. Salisbury, Ph.D., Cognitive Neuroscience Laboratory, McLean Hospital NBG21, 115 Mill Street, Belmont, MA 02478, USA. E-mail: dean_salisbury@hms.harvard.edu..

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1986; Roth & Cannon, 1972; Salisbury, Shenton, & McCarley 1999). Salisbury et al. (1994) and Weisbrod et al. (1997) showed that this reduced amplitude was not due to reduced information transfer. The performance of schizophrenic subjects could be approximated with that of controls by increasing the pitch separation and the intensity of the stimuli. This functional improvement was mirrored in the patients by reduction of the latency of P300 and reaction time. However, this functional manipulation had no effect on the amplitude of P300. Thus, from near threshold to suprathreshold stimulus values, P300 amplitude remained reduced in schizophrenia, but, by contrast, showed the expected increase in controls. These data suggested that the reduced P300 amplitude in schizophrenia was related to defective generator activity rather than to reduced information transfer or inattention.

Information transfer is multiplicative with stimulus meaning and subjective probability in Johnson's model (1986) and at suprathreshold values it is assumed to have a value of 1. Thus, variations in extraneous variables might not be expected to affect P300 at suprathreshold values. Consequently, investigations of how P300 is affected by stimulus characteristics that do not appear to affect performance at suprathreshold stimulus values, the portion of the stimulus parameter-P300 response curve that is apparently decoupled or nonlinear, have been fewer than investigations of effects at near threshold.

At suprathreshold stimulus variables, P300 is much less affected by stimulus parameters. However, it remains affected. One of the major contributions of Polich and colleagues has been the explication of how P300 is affected by stimulus parameters (e.g., ISI, intensity separation; Polich, 1987) and extraneous variables (e.g., time of day, food; Polich & Kok, 1995). One extraneous variable that may substantially affect P300 is the presence of a background mask. Although this feature of the stimulus field is typically varied between laboratories, to our knowledge only one study (Polich, Howard, & Starr, 1985) examined its effect. The presence of background noise was reported to increase P300 latency, but amplitude and scalp topography were not reported.

At suprathreshold stimulus values, P300 can be used as a index of the amount of attentional resources devoted to the task. In a typical resource allocation task, subjects perform two tasks at once. In detecting a target tone, for example, subjects will show poorer performance and delayed reaction times as the secondary task becomes more difficult (e.g., Tyler, Hertel, McCallum, & Ellis, 1979). Likewise, P300 amplitude to the target tone will decrease. This effect is thought to reflect the reduction of attentional resources devoted to tone detection as the other task become more difficult or resource consuming (Isreal, Wickens, & Donchin, 1979). It is unknown how resource allocation interacts with extraneous parameter effects on P300.

In this study, we examined the effect of background noise on P300 amplitude and latency when stimuli were suprathreshold. P300 was recorded in oddball tasks while subjects silently counted the presence of an easily detectable target tone. In one condition, they did so in the presence of background noise. In a second condition, they counted the identical target stimuli in the absence of background noise. The effects of background noise on performance, P300 latency, amplitude, and scalp topography were of primary interest.

Materials and Methods

Participants

Forty participants were recruited from newspaper advertisements (7 female, 1 left-handed). Participants were screened for age (18 to 55 years), normal hearing as assessed by audiometry from 500 Hz to 2 kHz, and negative history of seizures, head trauma, neurological disorder, and lifetime alcohol or drug dependence. The absence of a psychiatric diagnosis was determined via SCID-NP interview (Spitzer, Williams, Gibbon, & First, 1990). All participants gave written informed consent and were paid to participate.

All participants performed the Mini-Mental State Examination (Folstein, Folstein, & McHugh, 1975) to rule out any dementia or delirium, and the Information and Digits-forward and -backward subscales of the WAIS-R (Weschler, 1981) as a gross estimate of intellectual functioning.

Participants' mean age was 30.4 (9.6). Mean scores on the Mini-Mental (maximum of 30) was 29.4 (0.9). Mean scaled score on the WAIS-R Information subscale was 13.7 (2.7), and the mean scaled score on the WAIS-R digits test was 11.6 (2.3).

ERP Recording

Participants silently counted binaurally presented target tones (97-dB SPL, 1.5-kHz tones, 50-ms duration, 10 ms rise/fall, 15% of trials) among standard tones (1 kHz) under two stimulus conditions. The noise condition had 70-dB SPL white noise presented continuously. The no-noise condition had no background masking noise. Presentations were counterbalanced. Tones were presented over insert earphones with an ISI of 1.2 s. EEG activity was recorded through 28 tin electrodes in preconfigured caps (ElectroCap International) using a Neuroscience amplifier/stimulator and Neuroscan recording software. Electrode sites included all 10-20 sites excluding T1/2, and including Oz, FTC1/2, TCP1/2, PO1/2, and CP1/2. Linked earlobes were used as the reference and the forehead as ground. Two electrodes located medially to the right eye, one above and one below, were used to monitor vertical eye movements. Electrodes placed at the outer canthi of the eyes were used to monitor horizontal eye movements. All electrode impedances were below 3 KΩ, and the ears were matched within 1 KΩ. The EEG amplifier bandpass was 0.15 (6 dB/octave rolloff) to 40 Hz (36 dB/octave rolloff). Each epoch was of 900 ms duration, including a 100-ms prestimulus baseline, digitized at 3.5 ms/sample. Averaging and artifact rejection were done off-line according to an automated procedure. Within each 200-trial block, each epoch was convolved with a zero phase-shift digital low-pass filter at 8.5 Hz with a 24 dB/octave rolloff to remove ambient electrical noise, muscle artifact, and alpha contamination. Epochs from each electrode site were baseline corrected by subtraction of the average prestimulus voltage and corrected for eye movement artifact using regression-based weighting coefficients (Semlitsch, Anderer, Schuster, & Presslich, 1986). Subsequently, epochs that contained voltage exceeding ±50 μV at F7, F8, Fp1, or Fp2 were rejected. Averages were computed for the brain responses to target tones. Peak P300 amplitude and latency were measured at the most positive point from 250 to 650 ms at each recording site.

Analyses

A *t* test was used to assess the effect of background noise on detection accuracy. Repeated-measures ANOVA was used to test for effects of background noise on P300 amplitude and latency along the sagittal midline (Fz, Cz, Pz) and over lateral regions. Three regions were constructed for each hemisphere: frontal (F3/4, FTC1/2, C3/4); temporal (T3/4, TCP1/2, T5/6); and parietal (P3/4, CP1/2, PO1/2). The Huynh-Feldt epsilon was used to adjust degrees of freedom where appropriate.

Results

Behavior

Counting accuracy was calculated by the following formula: [#Targets - Absolute Value (#Count - #Targets)] /# Targets * 100. Accuracy was unaffected by the presence of background noise (no-noise: 97.5% (4.0), noise 97.3% (4.7), $t(39) = 0.22$, $p > .8$).

P300 Amplitude

The mean number of trials used to construct target averages did not differ significantly between conditions. Group grand averaged ERPs to target tones for the noise and no-noise conditions are presented in Figure 1. All values for amplitude and latency measures are provided in Table 1.

Midline sites (Fz, Cz, Pz)—Although P300 amplitude appeared slightly larger in the presence of background noise, this effect was not significant, $F(1,39) = 1.07$, $p > .3$. P300 was significantly larger posteriorly, $F(2,78) = 57.8$, $p < .001$, $\varepsilon = .84$. This voltage gradient was not significantly different between the noise and no-noise conditions, $p > .8$. The number of subjects showing an amplitude increase or an amplitude decrease at Pz was assessed via a sign test. Twenty-one of the 40 subjects showed a P300 amplitude increase in the presence of noise, and 19 showed an amplitude decrease in the presence of noise (Wilcoxon matched pairs signed ranks test, $Z = -0.50$, $p > .6$). Thus, the effect of background noise on P300 amplitude in this relatively large sample appears to be random and within normal measurement error variance.

Lateral regions (frontal, temporal, parietal)—Lateral regions are indicated in Figure 1. P300 amplitude was unaffected by the presence of background noise, $F(1,39) = 0.37$, $p > .5$. Lateral P300 amplitude was larger more posteriorly and superiorly, $F(2,78) = 81.3$, $p < .001$, $\varepsilon = .90$, and this topography was unaffected by the presence of background noise, $p > .4$. P300 amplitude was essentially symmetrical, $p > .3$.

P300 Latency

Midline sites—The presence of background noise increased P300 latency, $F(1,39) = 12.86$, $p = .001$. P300 latency was prolonged more posteriorly in both conditions, $F(2,78) = 12.15$, $p < .001$, $\varepsilon = .94$. The number of subjects showing a latency increase or a latency decrease at Pz was assessed via a sign test (Wilcoxon matched pairs signed ranks test, $Z = -3.20$, $p = .001$). Twenty-nine of 40 subjects (72.5%) showed a latency increase with noise, 6 (15%) showed a latency decrease with noise, and 5 (12.5%) showed no change (within the 3.5 ms digital bin).

Lateral regions—The results on P300 latency mirrored those from along the midline. P300 was significantly later in all regions with the presence of background noise, $F(1,39) = 14.11$, $p = .001$. P300 latency was greater more posteriorly, $F(2,78) = 33.23$, $p < .001$, $\varepsilon = .82$. There were no effects of hemisphere.

Conclusions

These results replicate the P300 latency prolongation by masking noise effect reported by Polich, Howard and Starr (1985), and extend that finding to show that P300 amplitude and scalp topography are unaffected by this factor. Latency changes in P300 attributable to normal aging did not moderate the change in P300 latency in the presence of background noise, as the effect persisted when covarying for age. The increase in P300 latency might be explained by a decrease in the information conveyed by the tones. As the subject had less information available, performance accuracy was maintained by increasing the depth of processing which is coupled to P300 latency increase (Kutas, McCarthy, & Donchin, 1977). However, the amplitude was unaffected. Although one might expect greater P300 amplitude with increased depth of processing (Ford, Pfefferbaum, Tinklenberg, & Kopell, 1982),itis plausible that although subjects modulated their depth of processing or allocated the greater resources necessary to detect the tones from the background, the increase in P300 amplitude this might engender may have been effectively counteracted by the reduction of P300 amplitude that might be expected with the reduction in information transfer. Although nonsignificant from peak measures, it appears that the descending phase of P300 was later in the noise condition, whereas the ascending phases appear identical between conditions. Thus, there may be some increase in P300 amplitude as expected with an increase in the attentional resources devoted to the task in the presence of background noise. However, the fact that whether P300 was larger in subjects in the presence of noise was essentially chance argues that amplitude was largely unaffected, by contrast with peak latency. Further, there were no significant correlations between task performance and P300 increase or decrease. The subjects that showed a P300 amplitude increase in the presence of noise did not also show better task performance than those subjects that showed a P300 amplitude decrease, $r = .17$, $p > .3$. Furthermore, the accuracy of the subjects that showed a P300 increase in the presence of noise was decreased by 0.20%, and the accuracy of the subjects that showed a P300 decrease in the presence of noise was decreased by 0.18%, again suggesting no association between the change in P300 amplitude and task performance. However, these results may be different for more complex tasks, for example, a three-tone discrimination task, or less readily discriminable target and standard tones.

These data suggest that the presence of background noise increases P300 latency, even when stimuli are easily detectable and targets are highly deviant. Thus, when comparing the results of different studies, particularly if those studies reveal an effect on latency, one must account for effects related to the presence or absence of background noise. Such apparently minor parametric differences may make comparisons of different studies more difficult than generally appreciated. By contrast, studies of P300 amplitude and scalp topography are likely unconfounded by the presence of background noise and may be more readily comparable.

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REFERENCES

Adler G, Adler J. Auditory stimulus processing at different stimulus intensities as reflected by auditory evoked potentials. Biological Psychiatry 1991;29:347–356. [PubMed: 2036478]

Begleiter, H.; Porgesz, B. The P300 component of the event-related brain potential in psychiatric patients. In: Cracco, R.; Bodis-Wollender, I., editors. Evoked potentials. Alan R. Liss; New York: 1986. p. 529-535.

Donchin E, Coles MGH. Is the P300 component a mani-festation of cognitive updating? Behavioral and Brain Sciences 1988;11:357–427.

Folstein MF, Folstein SE, McHugh PR. Mini-mental state: A practical method for grading the state of patients for the clinician. Journal of Psychiatric Research 1975;12:189–198. [PubMed: 1202204]

Ford J, Pfefferbaum A, Tinklenberg J, Kopell B. Effects of perceptual and cognitive difficulty on P3 and RT in young and old adults. Electroencephalography and Clinical Neurophysiology 1982;54:311–321. [PubMed: 6179758]

Hillyard SA, Squires K, Bauer J, Lindsey P. Evoked potential correlates of auditory signal detection. Science 1971;172:1357–1360. [PubMed: 5580218]

Isreal J, Wickens C, Donchin E. P300 amplitude changes during a tracking task as a function of continuous variations in tracking difficulty. Psychophysiology 1979;16:175.

Johnson R. A triarchic model of P300 amplitude. Psychophysiology 1986;23:367–384. [PubMed: 3774922]

Johnson R. On the neural generators of the P300 component of the event-related potential. Psychophysiology 1993;30:90–97. [PubMed: 8416066]

Kutas M, McCarthy G, Donchin M. Augmenting mental chronometry: The P300 as a measure of stimulus evaluation time. Science 1977;197:792–795. [PubMed: 887923]

Polich J. Task difficulty, probability, and inter-stimulus interval as determinants of P300 from auditory stimuli. Electroencephalography and Clinical Neurophysiology 1987;68:311–320. [PubMed: 2439311]

Polich J, Howard L, Starr A. Stimulus frequency and masking as determinants of P300 latency in event-related potentials from auditory stimuli. Biological Psychology 1985;21:309–318. [PubMed: 4096911]

Polich J, Kok A. Cognitive and biological determinants of P300: An integrative review. Biological Psychology 1995;41:103–146. [PubMed: 8534788]

Roth WT, Cannon E. Some features of the auditory evoked response in schizophrenics. Archives of General Psychiatry 1972;27:466–471. [PubMed: 5072716]

Salisbury DF, O'Donnell BF, McCarley RW, Nestor P, Faux S, Smith RS. Parametric manipulations of auditory stimuli differentially affect P3 amplitude in schizophrenics and controls. Psychophysiology 1994;31:29–36. [PubMed: 8146252]

Salisbury DF, Shenton ME, McCarley RW. P300 topography differs in schizophrenia and manic psychosis. Biological Psychiatry 1999;45:99–106.

Semlitsch HV, Anderer P, Schuster P, Presslich O. A solution for reliable and valid reduction of ocular artifacts, applied to the P300 ERP. Psychophysiology 1986;23:695–703. [PubMed: 3823345]

Spitzer, R.; Williams, J.; Gibbon, M.; First, M. The structured clinical interview for DSM-IIIR (SCID-NP)-non-patient edition. American Psychiatric Association; Washington, DC: 1990.

Sugg MJ, Polich J. P300 from auditory stimuli: Intensity and frequency effects. Biological Psychology 1995;41:255–269. [PubMed: 8608203]

Sutton S, Braren M, Zubin J, John ER. Evoked potential correlates of stimulus uncertainty. Science 1965;150:1187–1188. [PubMed: 5852977]

Tyler SW, Hertel PT, McCallum MC, Ellis HC. Cognitive effort and memory. Journal of Experimental Psychology: Human Learning and Memory 1979;5:607–617.

Wechsler, D. Manual for the Wechsler Adult Intelligence Scale-Revised. The Psychological Corp; Cleveland, OH: 1981.

Weisbrod M, Winkler S, Maier S, Hill H, Thomas C, Spitzer M. Left lateralized P300 amplitude deficit in schizophrenic patients depends on pitch disparity. Biological Psychiatry 1997;41:541–549. [PubMed: 9046986]

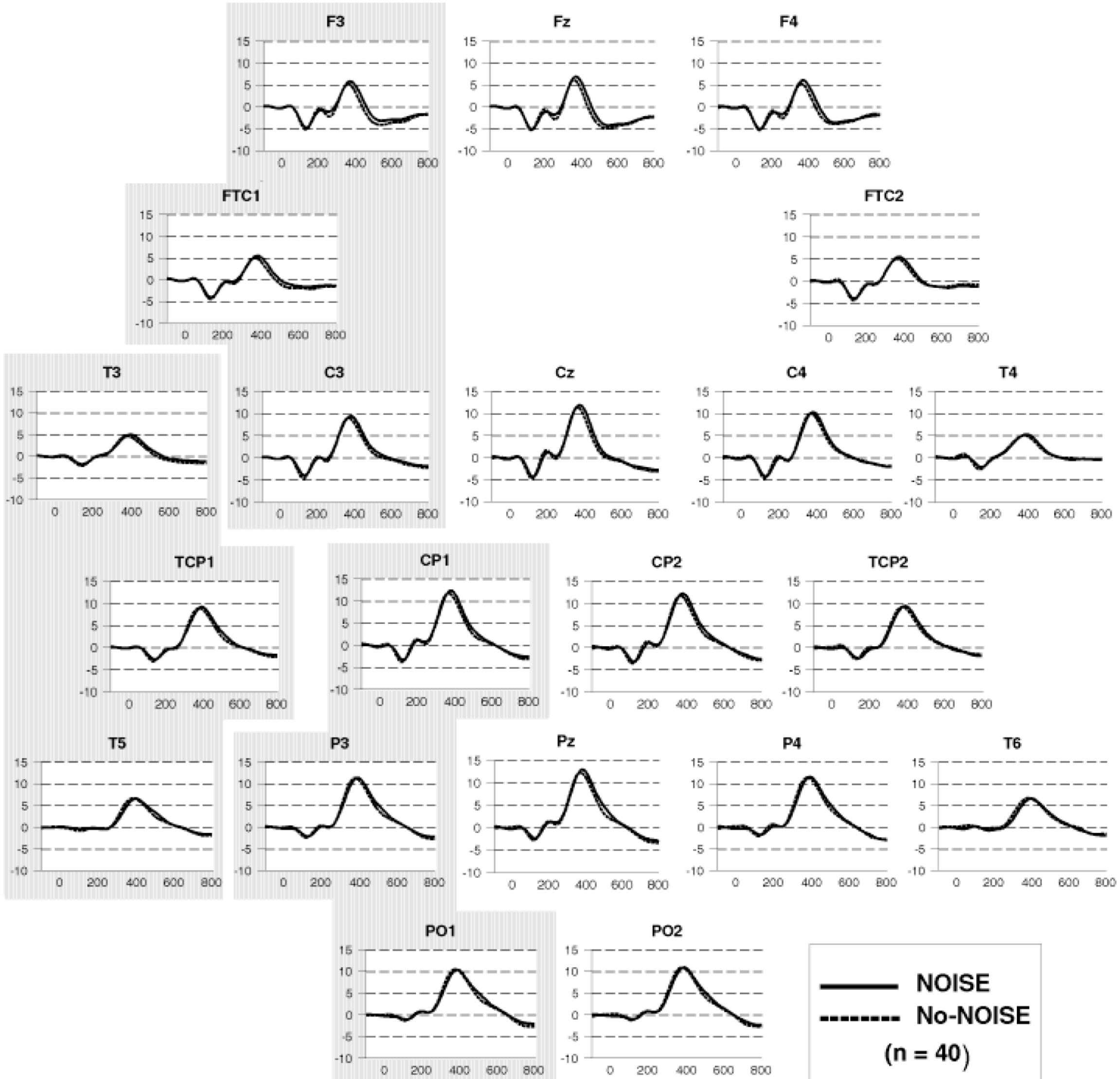

Figure 1.
ERPs elicited by identical target stimuli either in the presence of background white noise (noise) or in the absence of such masking noise (no-noise) from 21 cephalic recording sites. Shaded sites indicate lateral frontal, temporal, and parietal regions.

Table 1
P300 Amplitudes and Latencies

	Peak amplitude no-noise	Peak latency no-noise	Peak amplitude noise	Peak latency noise
Midline				
Fz	7.26 (5.8)	365.5 (29.5)	7.96 (6.3)	375.0 (28.1)
Cz	12.37 (7.4)	366.9 (29.9)	13.28 (7.0)	378.4 (31.6)
Pz	13.50 (8.0)	373.1 (30.3)	14.22 (7.6)	390.3 (35.8)
Frontal				
F3	6.13 (5.2)	365.5 (29.7)	6.66 (5.7)	375.1 (26.1)
F4	6.18 (5.3)	363.2 (25.0)	7.14 (5.3)	374.0 (29.5)
FTC1	5.77 (4.0)	367.3 (29.8)	6.21 (4.3)	381.5 (27.5)
FTC2	5.71 (3.9)	364.8 (28.6)	6.39 (3.2)	380.4 (34.4)
C3	9.92 (6.2)	371.7 (28.8)	10.34 (6.0)	383.5 (30.6)
C4	10.88 (6.3)	374.7 (28.1)	11.38 (5.2)	387.9 (28.9)
Temporal				
T3	5.33 (2.8)	376.4 (32.9)	5.53 (2.9)	394.9 (29.8)
T4	5.54 (3.0)	377.3 (34.2)	5.91 (2.2)	389.1 (30.1)
TCP1	9.74 (5.5)	380.5 (28.1)	9.98 (5.4)	396.6 (29.7)
TCP2	9.99 (5.1)	379.4 (28.1)	10.40 (4.5)	390.9 (32.4)
T5	7.49 (4.3)	388.2 (35.5)	7.26 (4.3)	402.2 (35.8)
T6	7.47 (4.0)	382.9 (36.1)	7.31 (4.0)	393.1 (30.1)
Parietal				
CP1	12.82 (7.4)	371.7 (30.4)	13.44 (6.5)	392.2 (65.0)
CP2	12.68 (7.0)	373.2 (28.9)	13.40 (6.1)	384.4 (31.7)
P3	12.35 (7.1)	378.9 (30.1)	12.37 (6.5)	395.5 (34.4)
P4	12.39 (6.7)	380.8 (29.5)	12.73 (6.4)	394.5 (30.1)
PO1	11.54 (7.4)	377.3 (32.0)	11.46 (6.4)	391.0 (33.6)
PO2	11.86 (7.2)	374.1 (40.5)	12.08 (6.9)	396.4 (45.1)

Amplitude values are mean peak in microvolts (*SD*). Latencies are mean peak in milliseconds (SD).