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BRAIN RESEARCH

Research Report

Identification and characterization of somatosensory off responses

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ABSTRACT

Event-related potentials (ERPs) have been recorded in response to the offset of sensory stimulation in both the auditory and visual modalities. The present experiment employed vibratory stimulation to characterize somatosensory ERPs in response to different duration stimuli. In two separate experiments, we recorded attended and unattended somatosensory ERPs to 70 Hz, sine wave stimuli using the following durations: 20 ms, 50 ms, 70 ms, 150 ms, 170 ms, 250 ms and 1000 ms. An oscillating coil delivered stimuli through a 'T-bar' to digits 2 and 3 of the right hand. The amplitude and latency measurements of P50, P100 and a later negative component (No1) were analyzed using MANOVA. There was no significant difference in the latency values of the P50 and P100, but as the duration increased, there was a significant increase ($P < 0.01$) in the latency of No1. No1 appeared 130 ms ± 9 ms following the offset of the stimulus. Amplitude values of the P50 and P100 components decreased as the stimulus duration increased and this effect became significant ($P < 0.05$) as the duration difference increased. Stimuli of 150 ms or greater evoked a negative baseline shift that persisted for the duration of the stimulus and area measurements in 7 out of the 10 subjects showed a significant increase in amplitude when the stimulus was attended. An intracranial case study supported these findings. The characteristics of the No1 component indicate it is a somatosensory *off* response, and it, in conjunction with the P50 and sustained potential, may reflect activity of a neural system that is responsive to changes in the tactile environment.

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1. Introduction

Short transient cortical responses to the onset and offset of a sensory stimulus have been reported for both the visual and auditory systems. However, the off response tends to be smaller and more difficult to obtain as it is often subsumed by earlier waveform components. It requires stimulus durations of greater than 500 ms to clearly characterize the off response in these two sensory modalities (Crevits et al., 1982; Hari et al., 1997). In the somatosensory system, there is evidence of individual on–off neurons in the somatosensory cortex of monkeys (Sur et al., 1984), but to date, there are no reports of an off response recorded from human subjects. One possible reason may lie with the type of stimulation most commonly used in the study of somatosensory-evoked potentials (SEPs).

In the somatosensory system, manipulation of the stimulus characteristics has been more limited owing to the use of

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direct electrical stimulation on the nerve. The majority of previous studies have utilized electrical stimulation to evoke SEPs, and this is the most common stimulus type used clinically (for a review, see Desmedt, 1988). One advantage of using electrical stimulation is that it bypasses sensory receptors and directly stimulates afferent nerves; thus, the temporal dispersion in the afferent volleys arriving at the cortex is small, and the resulting evoked potentials are large and distinct. However, there is a lack of specificity with regard to the type of fibers activated, and in bypassing the sensory receptors with an all-or-nothing activation, there is a loss of natural discrimination. It is also more difficult to apply prolonged stimulation. In the 1980s, mechanical stimulation with rapid rise times (such as tapping and vibration) was tested (Larson and Prevec, 1970, Onofrj et al., 1999), and the early/mid latency components were shown to closely resemble those elicited by electrical stimulation, though with a somewhat later latency and lower amplitude (Hämäläinen et al., 1990). However, unlike electrical stimulation, mechanical stimulation allows for easier manipulation of the stimulus duration and provides a controlled means of stimulating distinct groups of skin mechanoreceptors (Bolanowski et al., 1988, Valbo and Johansson, 1984). For example vibrotactile stimuli above 60 Hz excite predominantly the Pacinian receptors (RAII), while low-frequency stimuli are specific for non-Pacinian receptors (RAI) (Johansson et al., 1982). Mechanical stimulation is also better tolerated than electrical stimulation and more in keeping with 'normal' everyday tactile stimulation.

In this study, we measured somatosensory-evoked potentials to a range of stimulus durations using a high-frequency vibration applied to the fingers. We aimed to determine the presence of on–off responses similar to those reported for the auditory and visual modalities and present a case study where these potentials were recorded using intracranial subdural electrodes.

2. Results

2.1. *Study 1*

The latencies of the P50 and P100 components showed no significant difference between the different stimulus durations. However, the P50 component showed a significant difference between electrode locations ($F(5,40) = 51.79$ $P < 0.001$) with an increase in latency over the right scalp electrodes (ipsilateral to the side of stimulation). There was no significant difference in the P100 latency between electrode locations.

For the amplitudes of the P50 and P100 components repeated measure analysis indicates a significant decrease in amplitude with increasing duration ($F(5,40) = 15.80$ $P < 0.001$, $F(5,40) = 10.29$, $P < 0.001$ respectively) and between electrode locations ($F(5,40) = 9.68$ $P < 0.001$, $F(5,40) = 9.57$ $P < 0.001$) on the ipsilateral vs. contralateral hemisphere. There was no significant interaction between these effects. Component amplitudes were largest over the midline and contralateral hemisphere for all stimulus durations. However, Bonferroni corrected paired-samples *t* tests showed a significant difference in amplitude ($P < 0.05$) between the P50 and P100 amplitudes of each duration except between 20 ms and 50 ms, and between 150 ms and 170 ms (Fig. 1B).

For the No1 component, there was a significant difference in latency between durations ($F(5,40) = 74.63$, $P < 0.001$) (Figs. 1A and C) but no significant differences in latency between electrode locations. Repeated measures analysis also showed a significant difference in the amplitude across the different durations ($F(5,40) = 16.94$, $P < 0.001$) as well as significant differences between electrode locations ($F(5,40) = 5.32$, $p = 0.01$) in a manner similar to that of the P50 and P100 components. It peaked between 120 and 144 ms (average = 129.7 ms ± 9.1 ms) following the offset of the stimulus, with no significant difference between the different stimulus durations. The scalp distribution of this component was similar to that of the P100 component (Fig. 2A).

At the longer stimulus durations (150 ms+), a positive component (labeled Po1) was observed preceding No1 by 85 ms ± 4 ms but, in several subjects, was obscured by other waveform components. At the shorter durations, this component was not readily observable, most likely being subsumed by the P100 or N130 components.

At the longer durations, the waveform did not reach the baseline between the end of the P100/N130 components and the start of the Po1/No1 complex, rather there was a negative baseline shift that lasted throughout the duration of the stimulus. This phenomenon appeared maximally over the left centro-parietal region (Fig. 2B). The presence of a similar shift in the responses to the shorter durations is suggested by the broadening of the P50/P100 complex observed when comparing the responses to 20-ms, 50-ms and 70-ms stimulus durations (Fig. 1A). This may reflect a sustained potential similar to that reported in the auditory and visual systems (Picton et al., 1978a; Noda et al., 1998; Huettel et al., 2004).

In order to examine the possible effects of habituation or anticipation on the resulting waveforms, the grand average responses to the first and one hundredth stimulus were compared. There was no difference in the morphology or distribution of the responses. However, the response to the first stimulus did show a primacy effect, with the amplitude of the P50, P100 and No1 components being significantly higher ($P < 0.05$), and there was a clear P300 component that was not present in the later response. When the grand average response to the one hundredth stimulus was compared to that of the one hundred and fiftieth, there was no significant difference in latency, amplitude, scalp distribution or morphology.

2.2. *Study 2*

A series of waveforms similar to that described above was observed. The increase to a 1000-ms duration stimuli showed a clearer sustained potential, and there was a significant decrease in amplitude values of the P50/P100 components when compared to those obtained in the previous experiment ($P < 0.01$). This followed the trend observed in study 1, i.e., as the duration of the stimuli increased the amplitude of the P50 and P100 components decreased. The negative baseline shift observed at the shorter durations became more prominent

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