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# Is the somatosensory N250 related to deviance discrimination or conscious target detection?

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### Abstract

Effects of attention to, and probability of sudden changes in, repetitive stimuli on somatosensory evoked potentials (SEP) were studied. Low- (30 Hz) and high-frequency (140 Hz) vibratory stimuli were delivered in random order to the middle finger of the left hand with different presentation probabilities in different blocks. Also ignore conditions were administered.

In the ignore conditions, the probability had no effect on SEPs. However, when the standard stimuli were omitted, the "deviants" elicited small N140 and P300 deflections not observed in response to deviants when standards were also present. In the attention conditions, deviant stimuli (targets) elicited large N250 and P300 deflections which increased in amplitude with a decreased target probability. However, when subjects counted infrequently presented "deviants" alone (standards omitted) the enhanced N140 and the P300 with shortened latency were elicited, but no N250 wave could be found. At the ipsilateral side, a distinct N200 deflection was seen which could be the N250 with a shorter latency because of an easier task (detection instead of discrimination). The results might be interpreted as suggesting that the somatosensory N250 is related to conscious detection of target stimuli.

Keywords: Somatosensory evoked potentials; Somatosensory N250; Attention; Stimulus deviance; Deviance probability

# 1. Introduction

In active oddball or discrimination situations, infrequent auditory deviant (target) stimuli elicit negative mismatch (MMN), N2b, and late positive (P3) waves in human scalp recorded event-related potentials (ERPs) (for review, see Näätänen, 1992). In contrast to the MMN, the N2b and P3 are attention dependent, often not occurring in the ignore conditions (Näätänen, 1992), and analogous responses can be measured also to visual stimuli (Simson et al., 1977). The N2b has a fronto-central scalp distribution in the auditory and visual modalities which speaks for their non-specific generation (Näätänen, 1987), but some investigations have also yielded different distributions for the auditory and visual N2b (Simson et al., 1976, 1977; Alho et al., 1992; Woods et al., 1992; see also Halgren et al., 1995).

The N2b is usually followed by a P3a deflection, and therefore they are often called the N2b-P3a wave complex (Näätänen, 1992). The N2b-P3a association is quite strong (Courchesne et al., 1975; Loveless, 1986), but the N2b can occur also without the P3a (Knight, 1990; Ritter et al., 1992), and vice versa (Sams et al., 1985), suggesting different generators. However, if the discrimination has been successful, the most prominent deflection elicited by deviant/target stimuli is usually a centro-parietally distributed P3 (or P3b or "parietal slow wave") (Sams et al., 1985; Näätänen, 1992). Kropotov et al. (1995) recorded intracranially the N200/P300 complex to target tones in the active oddball situation from the prefrontal cortex, caudate nucleus, and cingulate gyrus where it was largest in amplitude. The large N200/P300 complex has been recorded intracranially also from the human anterior (Smith et al., 1990) and posterior cingulate and supramarginal gyri (Halgren et al., 1995). However, the relationship between these components and the scalp recorded ones is unclear.

Josiassen et al. (1982) found somatosensory N230 and P400 deflections to target electric stimuli delivered to the

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index or middle finger, which were not elicited by nontarget stimuli, those presented to the neighbouring finger or to the homologous fingers of the other hand. Furthermore, Ito et al. (1992) found similar (N240 and P300) components to rare target and also to rare non-target stimuli delivered to the other hand. Recently, Kujala et al. (1995) recorded quite similar auditory N2b-P3 and somatosensory N250-P300 complexes in selective attention conditions where subjects attended to infrequent auditory or somatosensory deviants, ignoring the stimuli of the other modality. In general, similarly to the auditory and visual N2b-P3, also the somatosensory N250-P300 seems to occur in active oddball or discrimination situations. However, the determinants of the somatosensory N250 are only very deficiently known. Therefore, in the present work, special interest was focussed on this component and its determinants. It was studied by manipulating the direction of attention and the probability of stimulus deviance in a condition where mechanical stimuli were delivered to the tip of the left middle finger.

### 2. Methods

Eight healthy right-handed subjects (ages 22-42 years; 1 male) participated in the experiments. During the recordings the subject was sitting comfortably in an electrically shielded room with the left hand supported by a vacuum cast on the instrumentation table. The stimuli, low- (30 Hz) and high-frequency (140 Hz) vibrations of 300 msec (including 30 msec rise and fall times), were delivered to the tip of the left middle finger at a rate of 1 burst/800 msec. The low and high vibration frequencies were selected to activate different submodality channels, nonpacinian and pacinian channels, respectively (see Vallbo and Johansson, 1984) and amplitudes (1000 and 80  $\mu$ m, respectively) to produce sensations of approximately the same intensity (by multiplying ( $\times 10$ ) sensation thresholds extrapolated from the previous data; see Kekoni et al., 1989). The stimuli were delivered by a probe of 8 mm diameter attached to the moving coil of an electromechanical vibrator (Bruel and Kjaer 4810). The amplitude was controlled by an accelerometer (Bruel and Kjaer 4339). The probe continuously touched the skin of the finger tip during the experiments.

In different stimulus blocks, the probabilities of the low- and high-frequency stimuli were 0.85/0.15 (standards/deviants), 0.5/0.5, and 0.0/1.0 (standards omitted), respectively. In the standards omitted condition, the timing of the "deviant" stimuli was exactly the same as in the conventional 0.85/0.15 paradigm. The total number of the "deviant" stimuli was identical (150) in all blocks.

In the attention conditions, subjects were instructed to count "deviant" ("target") stimuli by drawing a line on a

paper after each detected target stimulus. In the ignore conditions, subjects solved arithmetic tasks presented through earphones at a rate of about 7 tasks/min and wrote the results on a paper. Subjects were instructed to skip to the next problem if they did not have enough time to solve a task. Low-level white noise was presented through earphones during all conditions to mask possible sounds produced by the vibrator. Three stimulus blocks with the different probabilities were presented both in the ignore and attention conditions in a balanced order. Half of the subjects started with the ignore condition, and in the following attention condition the order of stimulus blocks was reversed. All subjects were tested on a subsequent day in the opposite order. In pilot experiments with 2 subjects, these tasks were also performed mentally with no motor activity. EEG responses with and without motor activity were quite similar. ERPs to stimuli with motor reactions were slightly smaller than without motor activity, but no differences in the distributions of the different components were found.

The EEG was recorded with Ag/AgCl electrodes from 7 scalp locations: F3, F4, C3', C4' (C3' and C4' 2 cm posterior to C3 and C4, respectively), Cz, P3, and P4. Voltage changes caused by eye movements and blinks were monitored with an electrode placed above the right eye. All electrodes were referred to the left mastoid. The analysis period was 550 msec including a 50 msec prestimulus period. The sampling rate was 250 Hz and the bandpass 0.1-100 Hz (-3 dB). The averaged SEPs were low-pass filtered (40 Hz). All epochs with a voltage change at any electrode exceeding  $\pm 75 \ \mu$ V were rejected from averaging.

The N140, N250, and P400 (or P300) deflections were determined from the individual SEPs and their peak amplitudes were measured from time windows 100–180, 180–280, and 280–480 msec, respectively. The N140 and N250 (when identifiable) were largest in amplitude at F4 and the P400 (or P300) at P4 in most cases. Therefore, because of the volume conduction principle, the amplitudes of these deflections from the other locations were measured at the peak latency defined at the afore-mentioned locations.

The effects of attention to, and probability of change in, stimuli on the different SEP deflections were studied with 2-factor analyses of variance for repeated measures including attention and electrode as well as the probability of deviant stimuli and electrode as factors. Changes in distributions (in lateral and antero-posterior directions) were analysed with post hoc paired t test when interactions between factors were obtained. The reported significances for the F values are those obtained after Greenhouse-Geisser correction when appropriate and then a correction coefficient  $\epsilon$  is given. However, the original degrees of freedom are presented for each analysis. The means and standard deviations of the SEP peak amplitudes and the effect of attention at the single electrodes are shown in Tables 1–3.

# 3. Results

### 3.1. Performance

Subjects found the stimuli of the different frequencies easily discriminable from each other in the attention conditions. On the average, they only missed 3.3% of the targets. The arithmetic tasks were demanding because of their rather fast presentation rate. Every subject failed to solve some tasks because of the short time allotted.

# 3.2. SEPs in the oddball situation

In the ignore condition, the SEPs to the deviants were rather flat (Fig. 1A), being smaller in amplitude than the



Fig. 1. Grand-average SEPs to high probability standard (0.85) low-frequency (30 Hz, 1000  $\mu$ m; thin line) and low probability deviant (0.15) high-frequency (140 Hz, 80  $\mu$ m; thick line) vibrations. Stimuli were delivered to the tip of the left middle finger while subjects were solving arithmetic tasks in the ignore (A) or counting deviant target stimuli in the attend condition (B).

.15/.85

Table 1

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| Electrode | N140        |             |          | N250      |             |           | P300      |           |             |
|-----------|-------------|-------------|----------|-----------|-------------|-----------|-----------|-----------|-------------|
|           | Ignore      | Attend      | F (1, 7) | Ignore    | Attend      | F (1, 7)  | Ignore    | Attend    | F (1, 7)    |
| F4        | - 0.4 (0.9) | - 2.4 (1.7) | 8.42 *   | 0.4(1.1)  | - 3.7 (3.6) | 14.37 * * | 0.2(1,1)  | 3.1 (3.3) | 6.39 *      |
| C4′       | 0.2 (0.9)   | - 1.5 (1.4) | 6.42 *   | 0.9 (0.5) | -1.9(1.8)   | 19.94 * * | 0.5 (0.3) | 5.1 (2.7) | 23.85 * *   |
| P4        | 0.6 (1.0)   | -0.8(1.1)   | 6.45 *   | 1.3 (0.7) | -0.9(1.1)   | 24.00 * * | 0.6 (0.5) | 5.4 (2.1) | 32.85 * * * |
| Cz        | 0.2 (1.0)   | -0.4(1.0)   | 2.60 ns  | 0.8 (0.9) | -2.6 (3.0)  | 13.62 * * | 0.5 (0.6) | 5.2 (2.7) | 23.59 * *   |
| F3        | -0.2(0.6)   | -1.3(1.3)   | 4.02 ns  | 0.0 (0.6) | -2.4(1.7)   | 19.17 **  | 0.1 (0.8) | 1.7 (2.8) | 2.90 ns     |
| C3′       | 0.2 (0.5)   | - 1.1 (1.2) | 6.25 *   | 0.4 (0.7) | - 2.5 (2.3) | 17.07 * * | 0.4 (0.5) | 3.7 (2.7) | 10.90 *     |
| P3        | 0.3 (0.6)   | -0.4(0.5)   | 6.28 *   | 0.4 (0.6) | -1.4(1.2)   | 19.67 * * | 0.4(0.4)  | 4.7 (2.7) | 20.03 * *   |

The mean peak amplitudes ( $\pm$ S.D.) of the SEP deflections (in  $\mu$ V) of 8 subjects to "deviant" stimuli in the oddball condition as well as the F values for the effects of attention separately for each electrode

\* P < 0.05; \*\* P < 0.01; \*\* P < 0.001.

corresponding responses to the standards. However, SEPs to standards remained almost unchanged when moving from the ignore condition to the attention condition, whereas SEPs to deviants clearly changed (cf., Fig. 1A and B).

In the attention condition, 3 late components, N140, N250, and P400, could be seen in SEPs to the deviants (Fig. 1B). The N140 (mean latency 141 msec) was largest at the contralateral frontal location. The N140 amplitude variation between the different electrodes was significant  $(F (6, 42) = 6.04, P = 0.02, \epsilon = 0.28889)$ . Further, the amplitude significantly increased (F (1, 7) = 6.79, P =0.04) when subjects counted deviant stimuli. The interaction between attention and electrode location was significant (F (6, 42) = 3.79, P = 0.04,  $\epsilon = 0.35983$ ). This enhancement was significantly larger at all contra- (F4, C4' and P4) than ipsilateral locations (F3, C3' and P3; t =2.531, P = 0.0392; t = 2.417, P = 0.0463; t = 2.513, P =0.0402). The N250 deflection (mean latency 249 msec) elicited by the deviants in the attention condition was quite distinct at all electrodes, except at P4 (Fig. 1B). The amplitude enhancement with attention was marked (F (1, (7) = 22.5, P = 0.002) at all electrodes (Table 1) and was significantly larger at the contralateral frontal than homologous ipsilateral location (t = 2.366, P = 0.0499). It was followed by a broadly distributed P400 with a mean peak latency of 388 msec (Fig. 1B). The P400 amplitude variation between the electrodes was significant (F (6, 42) = 6.5, P = 0.008,  $\epsilon = 0.35854$ ). The attention effect on the P400 amplitude was also significant (F (1, 7) = 20.67, P = 0.003). The interaction between attention and electrode was also significant (F (6, 42) = 4.06, P = 0.03,  $\epsilon = 0.43626$ ). The amplitude increase was significantly larger at the contralateral central than at the homologous ipsilateral location (t = 3.19, P = 0.0153). At the ipsilateral side, the increase was larger at the posterior P3 and C3' than at the anterior F3 (t = 3.289, P = 0.0133; t = 2.717, P = 0.0299).

### 3.3. SEPs to equiprobable stimuli

In the ignore condition, with equiprobable low-("standard") and high-frequency ("deviant") stimuli, the SEPs were quite similar to the corresponding responses in the oddball situation (cf., Figs. 2A and 1A). Nor was there any remarkable difference in the SEPs to the "standards" between the attention and ignore conditions (cf., Fig. 2B and A).

In the attention condition, the N250 and P400 could be seen in the SEPs to the "deviants" (Fig. 2B), but at a smaller amplitude than in the 0.85/0.15 condition (Fig. 1B). On the contrary, the N140 was of almost the same size and wave form as in the oddball condition, being largest at the contralateral frontal location (Table 2). The

Table 2

The mean peak amplitudes ( $\pm$ S.D.) of the SEP deflections (in  $\mu$ V) of 8 subjects to "deviant" stimuli in the equiprobability condition as well as the F values for the effects of attention separately for each electrode

| Electrode | N140        |             |          | N250      |             |           | P300        |           |          |
|-----------|-------------|-------------|----------|-----------|-------------|-----------|-------------|-----------|----------|
|           | Ignore      | Attend      | F (1, 7) | Ignore    | Attend      | F (1, 7)  | Ignore      | Attend    | F (1, 7) |
| F4        | - 0.2 (0.8) | -2.7 (1.7)  | 13.99 ** | 0.3 (0.5) | - 1.6 (1.4) | 17.12 * * | 0,1 (0.8)   | 1.3 (1.2) | 8.03 *   |
| C4′       | 0.2 (0.6)   | -1.1(1.1)   | 11.03 *  | 0.3 (0.5) | -0.1(0.4)   | 1.48 ns   | -0.1 (0.4)  | 2.4 (2.1) | 10.38 *  |
| P4        | 0.4 (0.5)   | -0.4(1.1)   | 4.66 ns  | 0.1 (0.6) | 0.4 (1.5)   | 0.40 ns   | -0.2 (0.5)  | 3.1 (3.0) | 9.96 *   |
| Cz        | 0.1 (0.8)   | -0.3(1.7)   | 0.44 ns  | 0.2 (0.8) | 0.0 (1.0)   | 0.08 ns   | - 0.2 (0.4) | 2.3 (2.1) | 9.04 *   |
| F3        | -0.1 (0.5)  | - 1.5 (1.2) | 9.10 *   | 0.0 (0.5) | - 1.2 (0.8) | 10.56 *   | -0.1 (0.6)  | 0.4 (1.3) | 0.81 ns  |
| C3′       | 0.2 (0.4)   | -0.9(1.1)   | 8.66 *   | 0.0 (0.5) | -0.7(1.1)   | 2.65 ns   | -0.1 (0.3)  | 1.9 (2.6) | 4.33 ns  |
| P3        | 0.3 (0.3)   | -0.3 (0.5)  | 10.15 *  | 0.0 (0.6) | 0.0 (0.3)   | 0.03 ns   | 0.0 (0.3)   | 2.5 (2.7) | 6.51 *   |

\* P < 0.05; \* \* P < 0.01.

variation between the electrodes was significant (F (6, 42) = 7.67, P = 0.004,  $\epsilon = 0.3664$ ). The N140 amplitude was larger in the attend than in the ignore condition (F (1, 7) = 9.48, P = 0.02). Also, the interaction between attention and electrodes was significant (F (6, 42) = 6.07, P = 0.008,  $\epsilon = 0.39654$ ). The enhancement was larger at the contralateral than at the ipsilateral frontal location (t = 2.974, P = 0.0207), and larger at the contralateral

frontal F4 electrode than at the contralateral posterior C4' and P4 locations (t = 3.603, P = 0.0087; t = 3.254, P = 0.014). In this equiprobability condition, the N250 (mean latency 262 msec) to attended "deviants" could be seen at the frontal and ipsilateral central locations (Fig. 2B). Its amplitude was significantly larger in the attend than in the ignore condition only at F4 and F3 (Table 2). The interaction between the recording site and attention was signifi-

-3 µV

0.5/0.5

# A. IGNORE



Fig. 2. Grand-average SEPs to equiprobably presented high- (140 Hz, 80  $\mu$ m; thick line) and low-frequency (30 Hz, 1000  $\mu$ m; thin line) vibrations. Stimuli were delivered to the tip of the left middle finger while subjects were solving arithmetic tasks in the ignore (A) or counting the high-frequency target stimuli in the attend condition (B).

cant (*F* (6, 42) = 6.69, *P* = 0.006,  $\epsilon$  = 0.38065). The enhancement was larger at the contralateral frontal F4 than at the posterior C4' and P4 locations (*t* = 5.038, *P* = 0.0015; *t* = 3.63, *P* = 0.0084); however, there was no significant change in lateral direction. The N250 was followed by a broadly distributed late P400 (mean latency 370 msec). Its amplitude was significantly increased by attention (*F* (1, 7) = 7.35, *P* = 0.03). The interaction between electrodes and condition was significant (*F* (6, 42) = 8.09, *P* = 0.006,  $\epsilon$  = 0.30293). The enhancement of P400 was larger at the

contralateral parietal than at the ipsilateral location (t = 3.072, P = 0.018), and larger at the posterior than at the frontal locations at both sides (P4 vs. F4 , t = 2.63, P = 0.0339; C4' vs. F4, t = 2.672, P = 0.0319; P3 vs. F3, t = 3.238, P = 0.0143; C3' vs. F3, t = 2.923, P = 0.0222).

3.4. SEPs to infrequent "deviants" when standards were omitted

Fig. 3 shows the grand-average SEPs to the highfrequency "deviant" stimuli when the low-frequency stan-

# 1.0/0.0



Fig. 3. Grand-average SEPs to infrequently presented "deviant" vibratory stimuli (140 Hz, 80  $\mu$ m) delivered to the tip of the left middle finger when the standard stimuli were omitted. Subjects were solving arithmetic tasks in the ignore (A) or counting the targets in the attend condition (B).

Table 3

| Electrode | N140        |             |          | P300      |           |             |  |
|-----------|-------------|-------------|----------|-----------|-----------|-------------|--|
|           | Ignore      | Attend      | F (1, 7) | Ignore    | Attend    | F (1, 7)    |  |
|           | - 2.3 (2.1) | - 5.0 (4.4) | 7.34 *   | 1.6 (1.5) | 3.2 (3.0) | 3.85 ns     |  |
| C4′       | - 1.2 (1.2) | - 2.8 (2.4) | 6.18 *   | 2.9 (1.4) | 5.4 (2.2) | 31.09 * * * |  |
| P4        | 0.0 (1.2)   | -0.9 (1.6)  | 3.65 ns  | 3.0 (1.9) | 6.7 (3.7) | 19.65 * *   |  |
| Cz        | -0.8(1.3)   | - 3.3 (4.8) | 2.95 ns  | 2.7 (1.5) | 5.0 (2.2) | 16.80 * *   |  |
| F3        | - 1.0 (1.2) | - 2.8 (3.3) | 4.05 ns  | 0.9 (1.2) | 1.9 (2.2) | 2.16 ns     |  |
| C3'       | -0.1(0.8)   | - 2.7 (3.5) | 5.16 ns  | 2.0 (1.3) | 3.7 (2.6) | 7.65 *      |  |
| Р3        | 0.4 (0.8)   | - 1.1 (1.9) | 5.25 ns  | 1.8 (1.3) | 4.6 (2.7) | 19.49 * *   |  |

The mean peak amplitudes ( $\pm$ S.D.) of the SEP deflections (in  $\mu$ V) of 8 subjects to "deviant" stimuli when standards were omitted as well as the F values for the effects of attention separately for each electrode

\* P < 0.05; \*\* P < 0.01; \*\*\* P < 0.001.

dard stimuli were omitted. The SEPs differed from the other SEPs of the present study in that there was a clear N140 (mean latency 146 msec) and P300 (mean latency 305 msec) also in the ignore condition (compare Figs. 3A, 2A and 1A).

The N140 amplitude increased (F (1, 7) = 5.59, P =0.05) when the subjects counted the rarely occurring (mean ISI = 5.3 sec) stimuli, being largest at the contralateral frontal location (Fig. 3 and Table 3). The amplitude variation between the different electrodes was marked (F (6,  $42) = 5.48, P = 0.02, \epsilon = 0.2884$ ). The SEPs in this attention condition differed from those in the other attention conditions in that there was no trace of the N250 wave. Instead, the N140 was followed by the P300 (mean latency 330 msec). There was, however, a little "bump" at the descending phase of N140, but it was not measurable at the contralateral side, because it was overlapped by the large N140. The P300 amplitude was increased with attention (F(1, 7) = 16.69, P = 0.005), being largest at the contralateral posterior location (Table 3). The amplitude variation between the different electrodes was significant  $(F (6, 42) = 7.94, P = 0.008, \epsilon = 0.27871)$ . The interaction effect between attention and electrode was also significant (F (6, 42) = 5.01, P = 0.011,  $\epsilon = 0.46556$ ). The enhancement with attention was larger at the ipsilateral parietal than at the frontal location (t = 3.761, P = 0.0071), but no significant changes in lateral direction caused by attention were observed.

#### 3.5. Effect of deviance probability on SEPs

Grand-average SEPs to ignored and attended "deviant" (target) stimuli presented with the different probabilities are superimposed in Fig. 4. SEPs were quite similar in the 0.85/0.15 and 0.5/0.5 ignore conditions (Fig. 4A). The probability had no marked effect on SEPs in these ignore conditions. In contrast, SEPs were different in the standard omitted (1.0/0.0) condition, including the clear N140 and P300 deflections, as already mentioned.

In the attend conditions, the probability had a distinct effect on SEPs (Fig. 4B). The N140 was smaller in

amplitude when it was elicited by target stimuli among standards (the 0.85/0.15 and 0.5/0.5 conditions) than when it was elicited by target stimuli presented without standards. However, this probability effect was not statistically significant, apparently because of great individual variation in amplitude. On the contrary, the probability effect on the P300/P400 amplitude was highly significant (F (2, 14) = 14.47, P = 0.0005,  $\epsilon$  = 0.96479). The interaction between the electrode and probability was not significant, indicating that the P300/P400 distribution did not depend on the target stimulus probability. The amplitudes of P400 were significantly larger in the 0.85/0.15 than in the 0.5/0.5 condition (F (1, 7) = 16.46, P = 0.0048).

The N250 occurred only when the target deviant stimulus was presented among standard stimuli, and its amplitude significantly increased when the probability decreased (F(1, 7) = 6.23, P = 0.0413). The interaction between the electrode and probability was not significant, suggesting independence of the N250 distribution of the target stimulus probability.

# 4. Discussion

### 4.1. SEPs to ignored stimuli

In the ignore conditions, the SEPs to the deviant stimuli were rather flat when the deviants were presented among the standards. However, when standard stimuli were omitted, the "deviants" elicited a small N140 and a late positive deflection (Fig. 4A), which were not found when standard stimuli were also presented in the block.

In contrast to our expectations, the SEPs in the ignore oddball situation to the low-frequency standard stimuli were larger in amplitude than to the high-frequency deviant stimuli (Fig. 1A), although the subjective intensities were equalled. SEPs should have been larger to deviants than to standards due to the physiological rate effect (Tomberg et al., 1989; Desmedt and Tomberg, 1991) because the mean ISI between successive deviants was considerably longer than between successive standards. The unexpected difference between these SEPs may be, at least partially, due to different cortical representations of pacinian and non-pacinian systems (Ferrington and Rowe, 1980; Burton and Carlson, 1986; Hämäläinen et al., 1988; Mogilnar et al., 1994), generating also differences in SEPs as has been shown previously (Hämäläinen et al., 1990).

The changes in SEPs in the standards omitted condition might be due to a temporal infrequency. Because the

A. IGNORE

omission of the standards, the unspecific part of the N140 had more time to recover than in the among standards conditions (see Näätänen, 1987; Tomberg et al., 1989). In addition, it is possible that the changes of the SEPs were, at least partially, related to sudden involuntary shifts of attention, because infrequent stimuli presented against a "silent" background had a strong orienting effect, subjects reporting that a stimulus sometimes caught their attention



**B. ATTEND** 



Fig. 4. Grand-average SEPs to 'deviant' stimuli when deviants were infrequently (0.15) presented (thick line) among standards (0.85), when 'standards' and "deviants" were equiprobable (dashed line), or when standards were omitted (thin line). Subjects were solving arithmetic tasks in the ignore (A) or counting the targets in the attend condition (B).

in spite of the rather demanding arithmetic task (cf., Desmedt and Robertson, 1977; Desmedt and Tomberg, 1991). This "attention leaking" interpretation (cf., Desmedt et al., 1977) is supported by the fact that the somatosensory N140 was followed by the P300 wave (Fig. 3A), which might index involuntary shifts of attention (Knight, 1984, 1985; Yamaguchi and Knight, 1991). This is also confirmed by the early onset of this positivity (Yamaguchi and Knight, 1991) and its preponderance on the contralateral hemisphere (Bruyant et al., 1993).

### 4.2. SEPs to attended targets

In the attend conditions, the late SEPs were more pronounced than in the ignore conditions (Fig. 4). The N140, N250 and P400 were elicited by the attended deviants in the 0.15/0.85 and 0.5/0.5 conditions. The large N140 and clearly earlier late positive (P300) deflections, but not the N250 wave, were elicited by the attended targets when the standards were omitted. All these late deflections were broadly and bilaterally distributed in the attend conditions and they were slightly larger at the contralateral side, being in good agreement with some previous mapping studies (Desmedt and Tomberg, 1989; García-Larrea et al., 1991; Bruyant et al., 1993). The N140 was most prominent at the contralateral frontal location in the attend conditions. That is concordant with the suggestion by Desmedt and Tomberg (1989) that the cognitive N140 reflects activation of area 46 and complex reciprocal interaction between posterior and prefrontal cortex and subcortical structures. The N250 was also largest at the contralateral frontal location and its fronto-central distribution (Fig. 4B) was of the same shape as distributions of the auditory N2b in many previous studies (for review, see Näätänen, 1992). This matches well with human intracranial recordings in which the large N200/P300 complex was observed from the human cingulate gyrus (Smith et al., 1990; Halgren et al., 1995; Kropotov et al., 1995). The P300/P400 was largest at the contralateral parietal location, supporting the idea of Bruyant et al. (1993) according to which the somatosensory P300 is dependent on the hemisphere receiving the P3-evoking stimulus.

### 4.2.1. Effects of attention

Previous studies have established that the N2b depends on the direction of attention (Näätänen and Gaillard, 1983). However, Ito et al. (1992) found somatosensory N240 and P300 deflections both in response to rare target and nontarget stimuli, suggesting that the somatosensory N240 could be elicited also by rare non-attended stimuli. The rare non-target stimuli were more infrequent (5%) than the target stimuli (15%). It may be that, because of this relative rarity, non-target stimuli sometimes caught attention. In addition, the N240-P300 to rare non-target stimuli was clearly smaller than to rare target stimuli, indicating attention dependence. The present results, too, support the idea of attention dependence of the somatosensory N250, because it occurred only in the attend conditions. Corroborating evidence is provided by previous results of Josiassen et al. (1982), Desmedt et al. (1983), Böning et al. (1989) and Desmedt and Tomberg (1989). Unfortunately, the somatosensory N250 (or N220, or N240) was rarely reported in previous studies, although it could be seen in published figures.

# 4.2.2. Detection vs. discrimination

It has been proposed that deviance is not a necessary condition for the elicitation of the N2b, whereas temporal infrequency might be a more important factor (Näätänen and Gaillard, 1983; Loveless, 1986). In the present results, when the probability of the deviant (target) in the attended stimulus sequence diminished, the amplitude of the somatosensory N250 considerably increased. Thus this amplitude seemed to be inversely related to temporal probability. However, temporal infrequency per se was not a sufficient condition, judging from the fact that, when the standards were omitted, large N140 and P300 deflections, but no N250 response, were elicited by the infrequent targets. Therefore, in light of the present data, stimulus change seems to be necessary for the generation of the somatosensory N250 response.

The present results could also be interpreted in another way. It is well known that the P3 depends on task difficulty (Duncan-Johnson and Donchin, 1982; Donchin et al., 1986). In the present study, the P300 latency markedly shortened when standards were omitted (from 388 to 330 msec). Obviously, this was due to the facilitation of the task performance, because the subjects had only to detect targets instead of discriminate between 2 different stimuli. A similar shortening was also observed for the auditory N2b when the discrimination between standard and deviant stimuli became easier (Sams et al., 1985). In the present results, there was a hardly perceivable "bump" in the descending phase of N140 when standards were omitted. This "bump" was more clearly seen at the ipsilateral (left) frontal and central locations, where it was the most negative deflection and not so much overlapped by the N140 as at the homologous contralateral sites. It could be the N250 with a latency of 200 msec that was also shortened, as was the P300 latency, by the fact that only detection was required instead of discrimination.

The N140 amplitude enhanced when standard stimuli were omitted as compared with other attend conditions. It could be that the target stimulus presented against a "silent" background is more arousing and, thus, generates a greater unspecific N140 (see Näätänen and Picton, 1987). Another possibility, not excluding the first one, is that because of the N250 latency shortening, the N140 and N200 (N250) are overlapping and partly summed together. If the shortening interpretation is true, it would mean that stimulus change is not necessary for the N250. This is in good agreement with previous results of auditory (Näätänen and Gaillard, 1983) and visual (Loveless, 1986) N2b generation. According to these results, the N2b could be elicited by infrequent isolated stimuli, too. This is also concordant with the result by Picton and Stuss (1980) that the P165-N2-P3a'is associated with signal detection.

According to Näätänen (1992), the critical borderline between the preconscious and conscious processes in discriminating a stimulus deviation lies between the N2b generator process and those of the subsequent positivities. The brain process generating the mismatch negativity is an automatic preconscious process, the auditory MMN being elicited by attended as well as ignored deviant stimuli (Näätänen et al., 1978). On the basis of the present results it is not possible to determine the moment of onset of conscious processing. It seems probable, however, that the somatosensory N250 is related to conscious target detection or deviant discrimination, because it was elicited only by attended target/deviant but not by similar ignored non-target/deviant stimuli. However, it still remains open whether stimulus change and, thus, deviance discrimination is necessary, or target detection alone is sufficient for the generation of the somatosensory N250.

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#### References

- Alho, K., Woods, D.L., Algazi, A. and Näätänen, R. (1992) Intermodal selective attention. II. Effects of attentional load on processing of auditory and visual stimuli in central space. Electroenceph. clin. Neurophysiol., 82: 356-368.
- Böning, J., Drechsler, F. and Neuhauser, B. (1989) Somatosensory event-related potentials and selective attention impairment in young chronic schizophrenics. Neuropsychobiology, 21: 146–151.
- Bruyant, P., García-Larrea, L. and Mauguière, F. (1993) Target side and scalp topography of the somatosensory P300. Electroenceph. clin. Neurophysiol., 88: 468-477.
- Burton, H. and Carlson, M. (1986) Second somatic sensory cortical area (SII) in a prosimian primate, *Galago crassicaudatus*. J. Comp. Neurol., 247: 200-220.
- Courchesne, E., Hillyard, S.A. and Galambos, R. (1975) Stimulus novelty, task relevance and the visual evoked potential in man. Electroenceph. clin. Neurophysiol., 39: 131-143.
- Desmedt, J.E. and Robertson, D. (1977) Differential enhancement of early and late components of the cerebral SEPs during fast sequential cognitive tasks in man. J. Physiol. (Lond.), 271: 761-782.
- Desmedt, J.E. and Tomberg, C. (1989) Mapping early somatosensory evoked potentials in selective attention: critical evaluation of control conditions used for titrating by difference the cognitive P30, P40, P100 and P140. Electroenceph. clin. Neurophysiol., 74: 321-346.
- Desmedt, J.E. and Tomberg, C. (1991) The search for "neutral" conditions for recording control event-related potentials in order to assess cognitive components to both irrelevant and relevant stimuli: evidence for short-latency cognitive somatosensory effects. In: C.H.M. Brunia,

G. Mulder and M.N. Verbaten (Eds.), Event-Related Brain Research (EEG Suppl. 42). Elsevier Science Publishers, Amsterdam, pp. 210-221.

- Desmedt, J.E., Robertson, D., Brunko, E. and Debecker, J. (1977) Somatosensory decision tasks in man: early and late components of the cerebral potentials evoked by stimulation of different fingers in random sequences. Electroenceph. clin. Neurophysiol., 43: 404-415.
- Desmedt, J.E., Nguyen, T.H. and Bourguet, M. (1983) The cognitive P40, N60 and P100 components of somatosensory evoked potentials and the earliest electrical signs of sensory processing in man. Electroenceph. clin. Neurophysiol., 56: 272-282.
- Donchin, E., Kramer, A.F. and Wickens, C. (1986) Applications of brain event-related potentials to problems in engineering psychology. In: M.G.H. Coles, E. Donchin and S.W. Porges (Eds.), Psychophysiology: Systems, Processes, and Applications. Guilford Press, New York, pp. 702-778.
- Duncan-Johnson, C.C. and Donchin, E. (1982) The P300 component of the event-related brain potential as an index of information processing. Biol. Psychol., 14: 1-52.
- Ferrington, D.G. and Rowe, M.J. (1980) Differential contributions on coding of cutaneous vibratory information by cortical somatosensory areas I and II. J. Neurophysiol., 43: 310-331.
- García-Larrea, L., Bastuji, H. and Mauguière, F. (1991) Mapping study of somatosensory evoked potentials during selective spatial attention. Electroenceph. clin. Neurophysiol., 80: 201-214.
- Halgren, E., Baudena, B., Clarke, J.M., Heit, G., Liégeois, C., Chauvel, P. and Musolino, A. (1995) Intracerebral potentials to rare target and distractor auditory and visual stimuli. I. Superior temporal plane and parietal lobe. Electroenceph. clin. Neurophysiol., 94: 191-220.
- Hämäläinen, H., Sams, M., Pertovaara, A., Carlson, S., Reinikainen, K. and Näätänen, R. (1988) Different functional roles of SI and SII somatosensory cortices as reflected by evoked potentials and multiple-unit responses to mechanical stimulation in awake monkey. Neurosci. Res. Commun., 2: 143–150.
- Hämäläinen, H., Kekoni, J., Sams, M., Reinikainen, K. and Näätänen, R. (1990) Human somatosensory evoked potentials to mechanical pulses and vibration: contributions of SI and SII somatosensory cortices to P50 and P100 components. Electroenceph. clin. Neurophysiol., 75: 13-21.
- Ito, J., Shibasaki, H. and Kimura, J. (1992) Somatosensory event-related potentials following different stimulus conditions. Int. J. Neurosci., 65: 239-246.
- Josiassen, R.C., Chagass, C., Roemer, R.A., Ercegovac, D.V. and Straumanis, J.J. (1982) Somatosensory evoked potential changes with a selective attention task. Psychophysiology, 19: 146–159.
- Kekoni, J., Hämäläinen, H., Rautio, J. and Tukeva, T. (1989) Mechanical sensibility of the sole of the foot determined with vibratory stimuli of varying frequency. Exp. Brain Res., 78: 419–424.
- Knight, R.T. (1984) Decreased response to novel stimuli after prefrontal lesions in man. Electroenceph. clin. Neurophysiol., 59: 9–20.
- Knight, R.T. (1985) Electrophysiology in behavioral neurology. In: M.-M. Mesulam (Ed.), Principles of Behavioral Neurology. Davis, Philadelphia, PA, pp. 327-346.
- Knight, R.T. (1990) Neural mechanisms of event-related potentials: evidence from human lesion studies. In: J.W. Rohrbaugh, R. Parasuraman and R. Johnson, Jr. (Eds.), Event-Related Brain Potentials: Basic Issues and Applications. Oxford University Press, New York, pp. 3-18.
- Kropotov, J.D., Näätänen, R., Sevostianov, A.V., Alho, K., Reinikainen, K. and Kropotova, O.V. (1995) Mismatch negativity to auditory stimulus change recorded from the human temporal cortex. Psychophysiology, in press.
- Kujala, T., Alho, K., Kekoni, J., Hämäläinen, H., Reinikainen, K. and Näätänen, R. (1995) Auditory and somatosensory event-related brain potentials in early blind humans. Exp. Brain Res., 104: 519–526.
- Loveless, N.E. (1986) Potentials evoked by temporal deviance. Biol. Psychol., 22: 149–167.

- Mogilnar, A., Nomura, M., Ribary, U., Jagow, R., Lado, F., Rusinek, H. and Llinás, R. (1994) Neuromagnetic studies of the lip area of primary somatosensory cortex in humans: evidence for oscillotopic organization. Exp. Brain Res., 99: 137–147.
- Näätänen, R. (1987) Event-related potentials in research of cognitive process – a classification of components. In: E. Meer and J. Hoffman (Eds.), Knowledge Aided Information Processing. Elsevier Science Publishers, Amsterdam, pp. 241–273.
- Näätänen, R. (1992) Attention and Brain Function. Lawrence Erlbaum, Hillsdale, NJ.
- Näätänen, R. and Gaillard, A.W.K. (1983) The orienting reflex and the N2 deflection of the event-related potential (ERP). In: A.W.K. Gaillard and W. Ritter (Eds.), Tutorials in ERP Research: Endogenous Components. North-Holland Publ., Amsterdam, pp. 119–141.
- Näätänen, R. and Picton, T. (1987) The N1 wave of the human electric and magnetic response to sound: a review and analysis of the component structure. Psychophysiology, 24: 375–425.
- Näätänen, R., Gaillard, A.W.K. and Mäntysalo, S. (1978) Early selective attention effect on evoked potential reinterpreted. Acta Psychol. (Amst.), 42: 313–329.
- Picton, T.W. and Stuss, D.T. (1980) The component structure of the human event-related potentials. In: H.H. Kornhuber and L. Deecke (Eds.), Motivation, Motor and Sensory Processes of the Brain: Electrical Potentials, Behavior and Clinical Use. Elsevier, Amsterdam, pp. 17-49.
- Ritter, W., Paavilainen, P., Lavikainen, J., Reinikainen, K., Alho, K., Sams, M. and Näätänen, R. (1992) Event-related potentials to repetition and change to auditory stimuli. Electroenceph. clin. Neurophysiol., 83: 306-321.

- Sams, M., Paavilainen, P., Alho, K. and Näätänen, R. (1985) Auditory frequency discrimination and event-related potentials. Electroenceph. clin. Neurophysiol., 62: 437–448.
- Simson, R., Vaughan, Jr., H.G. and Ritter, W. (1976) The scalp topograhy of potentials associated with missing visual or auditory stimuli. Electroenceph. clin. Neurophysiol., 40: 33-42.
- Simson, R., Vaughan, Jr., H.G. and Ritter, W. (1977) The scalp topography of potentials in auditory and visual discrimination tasks. Electroenceph. clin. Neurophysiol., 42: 528-535.
- Smith, M.E., Halgren, E., Sokolik, M., Baudena, P., Musolino, A., Liégeois-Chauvel, C. and Chauvel, P. (1990) The intracranial topography of the P3 event-related potential elicited during auditory oddball. Electroenceph. clin. Neurophysiol., 76: 235-248.
- Tomberg, C., Desmedt, J.E., Ozaki, I., Nguyen, T.H. and Chalkin, V. (1989) Mapping somatosensory evoked potentials to finger stimulation at intervals of 450 to 4000 msec and the issue of habituation when assessing early cognitive components. Electroenceph. clin. Neurophysiol., 74: 347–358.
- Vallbo, Å.B. and Johansson, R.S. (1984) Properties of cutaneous mechanoreceptors in the human hand related to touch sensation. Hum. Neurobiol., 3: 3-14.
- Woods, D.L., Alho, K. and Algazi, A. (1992) Intermodal selective attention. I. Effects on event-related potentials to lateralized auditory and visual stimuli. Electroenceph. clin. Neurophysiol., 82: 341–355.
- Yamaguchi, S. and Knight, R.T. (1991) P300 generation by novel somatosensory stimuli. Electroenceph. clin. Neurophysiol., 78: 50-55.