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# P300 COMPONENTS TO FREQUENT STANDARD STIMULI IN A 3-TONE PARADIGM REFLECT TASK STRATEGY

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## Introduction

In traditional oddball paradigms, the P300 amplitude varies as an inverse function of the probability of task-relevant stimuli[1]. Studies using three or more tones have revealed that infrequent target stimuli elicit parietal maximum P300s, while infrequent non-targets elicit central maximum P300s and frequent non-targets elicit no P300[2,3,4,7,8]. Recently, Donchin and his colleagues[5,6] have suggested that the P300 may be a manifestation of the processes of maintaining or updating the model of the environment in working memory. Klein et al.[5] have reported that the P300s elicited by the infrequent target tone are small or absent in subjects with absolute pitch during an auditory oddball paradigm. They interpreted this phenomenon as indicating that subjects with absolute pitch may not need to maintain or update the representations of infrequently occurring events in their working memories.

According to Donchin's hypothesis, P300s may be elicited by stimuli which are necessary for maintaining or updating the model of the environment in working memory, even though these are frequent irrelevant stimuli. In this study, we investigated the probability of P300s being elicited by frequent irrelevant stimuli during a three-tone paradigm.

## Methods

Nine healthy male volunteers were subjects in this study. Their mean age was 28.6 (range 23-37) years. All subjects were university graduates. Three subjects were judged as mixed handed, while the others as right handed.

A three-tone paradigm was employed consisting of a series of 300 tone bursts of 150 msec duration delivered at 2 sec intervals. The series included tones at 970 Hz, 1000 Hz and 1030 Hz in random sequence. The 1000-Hz tone occurred with a probability of .66 (frequent), and each of the 970-Hz and 1030-Hz tones occurred .17 of the time (infrequent). Tones were delivered at 50 dB-SL binaurally through headphones.

In the first run, subjects passively listened to the series of tones (No Task). In the second and third runs, subjects were

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required to count silently the total number of one of the two types of infrequent tones as the target in one run (Count). In the next two runs, subjects pressed a lever upon detection of the targets as accurately as possible before the appearance of the next tone (Accuracy). In the last two runs, subjects pressed a lever as accurately and fast as possible (Speed). Hence, each subject performed two runs for the two different targets in each of three active conditions (Count, Accuracy, Speed). In runs when the target was the 970-Hz tone, they pressed the lever to the right, with the thumb and index fingers of the right hand; similarly to the left for the 1030-Hz targets.

EEGs derived from the Fz, Cz and Pz regions with Ag/AgCl electrodes referred to linked earlobe electrodes (time constant, 0.3 sec; without a high cut-off filter) were recorded on FM tape. Trials on which the EEG exceeded 100 uV at any electrode site were rejected. EEG data were then digitized off-line with a sampling frequency of 500 Hz, from 128 msec preceding stimulus-onset to 896 msec post-stimulus. Individual data for each type of stimulus from each electrode in each run were averaged separately. In the Accuracy and Speed conditions, data with incorrect responses (omission errors or commission errors) were rejected in averaging. These averaged waveforms were smoothed with a digital filter (moving average method; width of data window: 50 points) to minimize any alpha activity in the record. The P300 component was defined as the peak amplitude relative to the baseline and was measured within a latency window of 250-600 msec. The baseline was determined as the mean voltage over the 128 msec period before stimulus onset.

## Results

Table I shows the behavioral data from the three active conditions. Commission error rates for infrequent non-target tones were greater in the Accuracy condition than in the Speed condition, while total error rates were almost equal in both conditions. Error indices were almost equal in the three active conditions. Median RTs (reaction times) were 200 msec faster in the Speed condition than in the Accuracy condition.

Table I. Behavioral data from the three active conditions.

| | Omission Error | Commission Error | | Total Error | Error Index | Median RT |
|---|---|---|---|---|---|---|
| | | IF-NT | F-NT | | | |
| Count (N=9×2) | — | — | — | — | 9.9%<br>(9.8) | — |
| Accuracy (N=9×2) | 12.2%<br>(20.3) | 0.6% *<br>(2.0) | 0.1%<br>(0.2) | 2.1%<br>(3.3) | 11.7%<br>(18.8) | 704 ms *<br>(123) |
| Speed (N=9×2) | 7.5%<br>(7.7) | 4.6% *<br>(5.2) | 1.2%<br>(3.5) | 2.6%<br>(3.3) | 10.1%<br>(17.8) | 510 ms *<br>(65) |

*: $p<0.05$ (paited t-test, 2-tailed). IF-NT : Infrequent non-target. F-NT : Frequent non-target.
Error Index (Count)=(| number of target − subject's answer |/number of target) × 100
Error Index (Accuracy, Speed) = (| commission error − omission error |/number of target) × 100

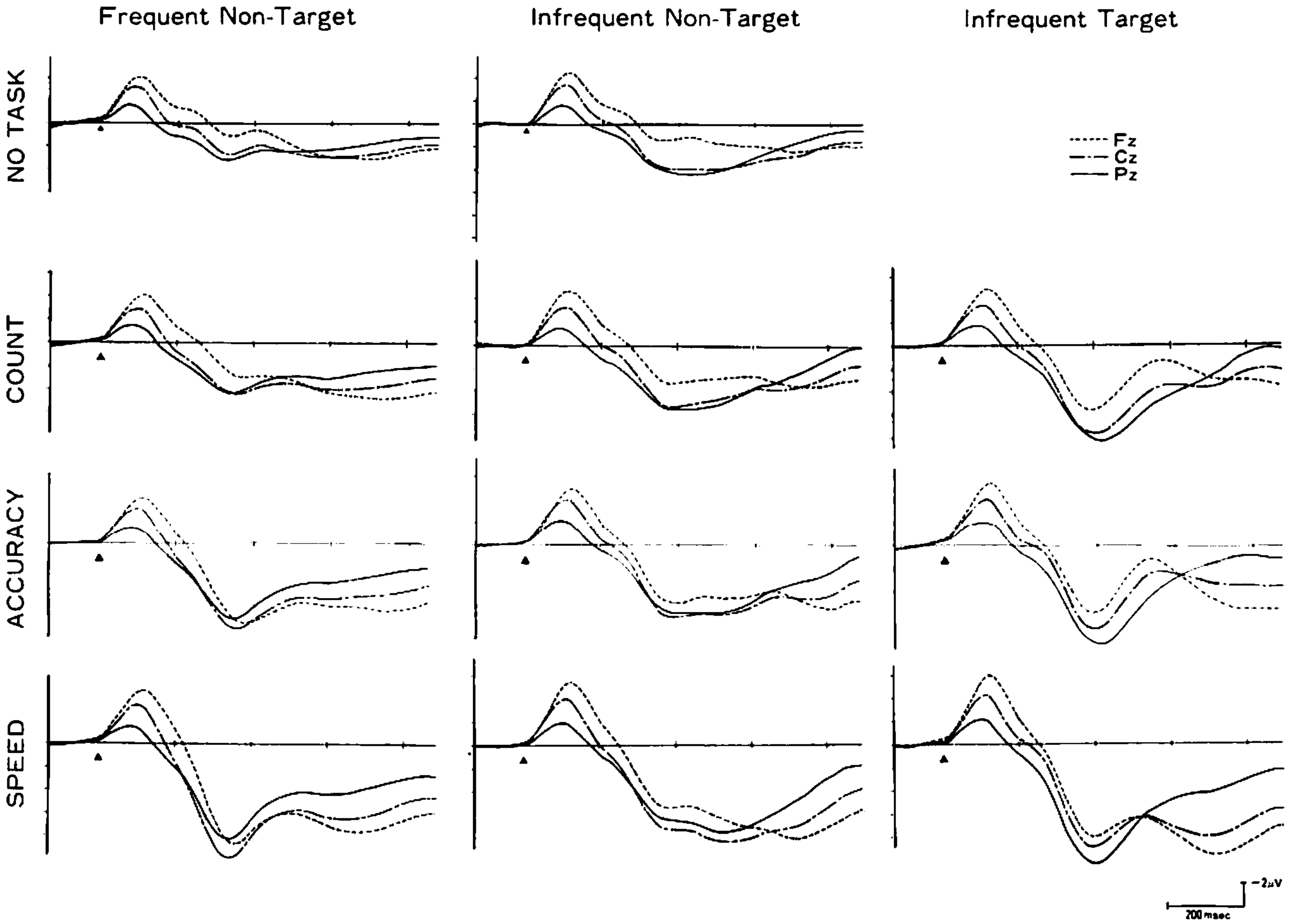

Fig. 1. Grand-average ERP waveforms. Filled triangles in this and the following figures indicate stimulus-onset.

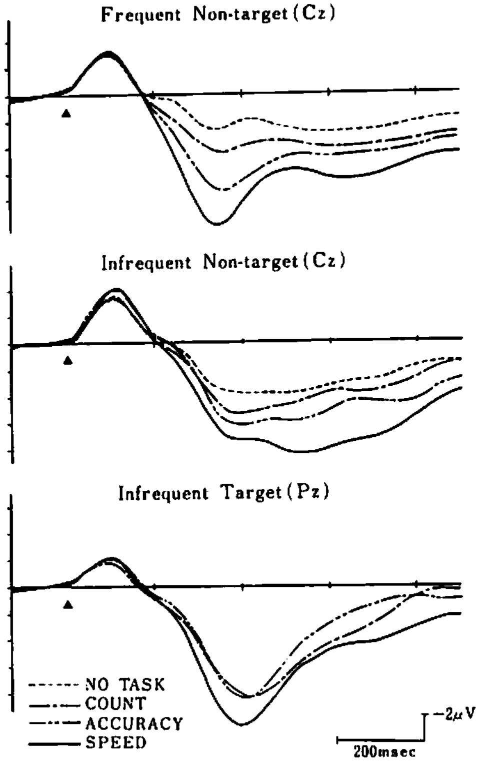

Fig. 2. Grand-average ERP waveforms in the dominant regions for each type of stimuli.

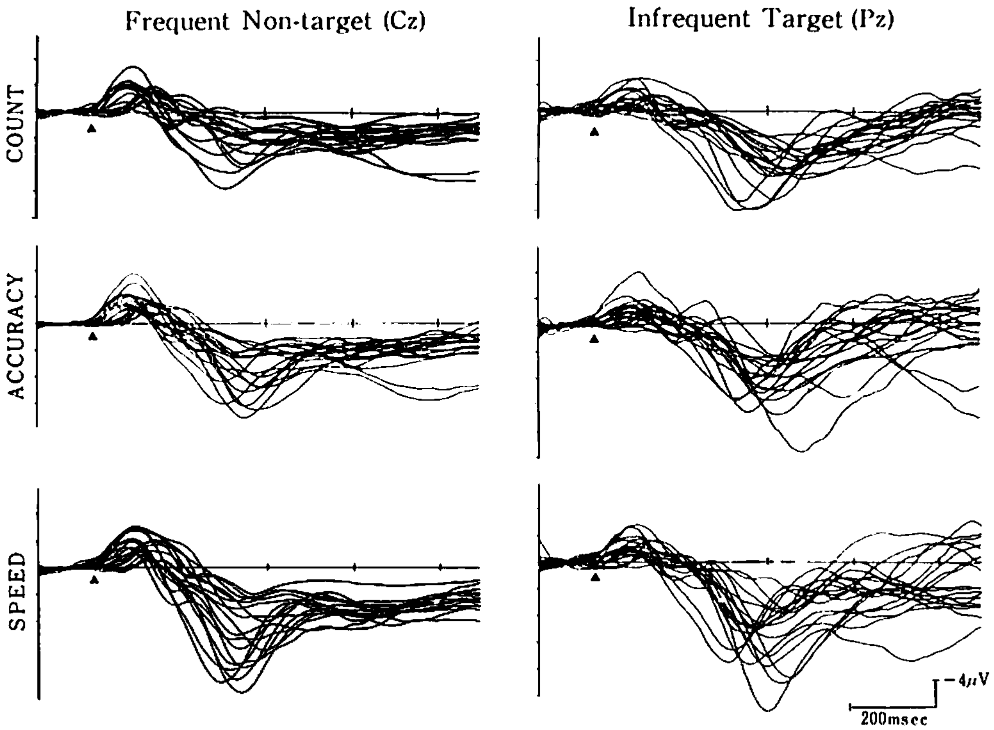

Fig. 3. Individual ERP waveforms elicited by the frequent non-target and the infrequent target tones in the three active conditions.

Fig. 1 shows the grand-average ERP waveforms for each type of stimulus from each electrode in each condition. In the No-Task condition, infrequent tones elicited larger late positive components than frequent tones. In the three active conditions, the infrequent targets elicited parietal dominant P300 components, with the frequent non-targets eliciting centro-frontal dominant P300s. Infrequent non-targets elicited centro-parietal dominant prolonged late positive components.

Fig. 2 shows the grand-average ERP waveforms at the dominant electrode sites for each type of stimulus. Experimental conditions most strongly affected the amplitudes of P300 for the frequent non-targets. The amplitude of P300s for the frequent non-targets increased sequentially with experimental conditions, and their latencies were approximately 350 msec in the three conditions (Count, 4.5 µV, 356 msec; Accuracy, 7.4 µV, 358 msec; Speed, 10.1 µV, 346 msec). The latencies of the P300s for the infrequent targets were approximately 400 msec in the three conditions and the amplitude of those in the Speed condition (10.6 µV, 398 msec) was larger than for those in the Count (8.4 µV, 418 msec) or in the Accuracy (8.5 µV, 408 msec) condition.

Fig. 3 shows the individual subject waveforms for both P300s. Table II shows the mean amplitudes and latencies for both P300s. The P300s for the frequent non-targets were smaller in amplitude and faster in latency than those for the infrequent targets in the three conditions. The difference in amplitude between the two P300s decreased and the latency difference increased sequentially with the experimental conditions. Thus, in the Speed condition, the P300 latencies for the frequent non-targets were 50 msec faster than those for the infrequent targets, while the amplitudes of the two P300s were nearly equal.

Table II. Amplitudes and latencies for both P300s in the three active conditions.

| | | COUNT | ACCURACY | SPEED |
|---|---|---|---|---|
| Frequent Non-target(Cz) | Amplitude(µV) | 5.1±2.8 | 8.0±3.7 | 10.7±5.1 |
| | Latency(msec) | 411±94 | 364±41 | 348±27 |
| Infrequent Target(Pz) | Amplitude(µV) | 9.6±3.1 | 9.7±3.7 | 12.4±4.5 |
| | Latency(msec) | 440±63 | 401±44 | 398±50 |

*: $p<0.05$ (paired t-test, 2-tailed).

## Discussion

Frequent non-target stimuli elicited clear P300 components with a central maximum distribution in these normal subjects. The latencies were 50 msec faster than those for infrequent targets.

Table III. The structure of stimuli in previous three or more tone paradigms.

| | STIMULI | TARGET |
|---|---|---|
| Johnson & Donchin | 1000Hz(33%), 1400Hz(33%), 1800Hz(33%) | 1000Hz |
| Näätänen et al. | 978Hz(2%), 1004Hz(95%), 1034Hz(2%), 1404Hz(1%) | 978Hz/1034Hz/978Hz+1034Hz+1404Hz |
| Fitzgerald & Picton | 1) 1000Hz(80%), 1050Hz(10%), 1500Hz(10%)<br>2) 1000Hz(80%), 1025Hz(5%), 1050Hz(5%), 1100Hz(5%), 1500Hz(5%)<br>3) 1000Hz(80.5%), 1050Hz(1.5%), 1200Hz(4.5%), 1800Hz(13.5%)<br>4) 1000Hz(80.5%), 1050Hz(13.5%), 1200Hz(4.5%), 1800Hz(1.5%) | 1050Hz+1500Hz<br>1025Hz+1050Hz+1100Hz+1500Hz<br>1050Hz+1200Hz+1800Hz<br>1050Hz+1200Hz+1800Hz |
| Friedman | 700Hz(17%), 1000Hz(66%), Missing Stimulus(17%) | 700Hz/MS |
| Pfefferbaum et al. | 1000Hz(72%), 2000Hz(14%) | 500Hz/2000Hz |

Several studies[2,3,4,7,8] have undertaken an investigation of ERPs during discrimination tasks with three or more tones. All of these studies have reported that infrequent target stimuli elicited parietal maximum P300s, while infrequent non-target stimuli elicited central P300s. However, none of these reports have demonstrated that P300s are elicited by frequent non-targets. The paradigms of previous reports differ from our paradigm (see Table III). The target stimuli of the Johnson and Donchin[4], the Friedman[3] and the Pfefferbaum et al.[8] paradigms were easier to discriminate from their non-target stimuli than was the case in our study (i.e., a 30 Hz difference). In Fitzgerald and Picton's study[2], frequent stimuli were always the lowest-pitched tone and subjects were required to make one type of response to all types of infrequent stimuli. Thus, their paradigm was rather similar to an oddball paradigm. The degree of difficulty in discriminating a 30 Hz difference between tones is identical to both Näätänen et al.'s[7] and the current study. However, the probability of the infrequent stimuli in Naatanen et al. was extremely low.

Our paradigm (1) indicated difficulties in discriminating a 30 Hz difference between tones; (2) utilized the frequent tone as a middle tone in between the two infrequent tones; and (3) ensured that the probability of the infrequent tone was not extremely low. These characteristics seemingly compelled the subjects to maintain or update the representation of the frequent 1000-Hz tone in their working memories as a necessary standard to judge the infrequent tones as higher or lower than the standard. Such a speculation is supported by the subjects' reports that they always remembered and confirmed the middle tone and that they judged the high or low tone by comparing it to the middle tone. According to Donchin's hypothesis[6], Klein et al.'s[5] and our results equally suggest that P300s are elicited by the frequent non-target stimuli if they are necessary for maintaining or updating the model of the environment in the working memory, and that P300s are not elicited by the target stimuli if they are not necessary for the updating process. Above all, the appearance of P300 for frequent tones could be indicative of an effective utilization of frequent stimuli as a necessary standard for the construction of an appropriate task-performing strategy.

The experimental condition most affected the amplitude of P300s elicited by the frequent stimuli. However, it is not clear whether this effect is due to the difference between the three conditions or due to the sequencing, since the order of the three conditions was not randomized. If this effect were due to sequencing, the amplitude of P300s elicited by the frequent stimuli might be an index of the subjects' learning of a task-performing strategy utilizing frequent stimuli as a standard.

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