The auditory P3 from passive and active three-stimulus oddball paradigm

Eligiusz Wronka[1,2]*, **Jan Kaiser**[1], **and Anton M.L. Coenen**[2]

[1]Institute of Psychology, Jagiellonian University, Kraków, Poland, *Email: eli@apple.phils.uj.edu.pl; [2]NICI, Department of Biological Psychology, Radboud University Nijmegen, Nijmegen, The Netherlands

The aim of this study was the comparison of basic characteristics of the P3 subcomponents elicited in passive and active versions of the auditory oddball paradigm. A 3-stimulus oddball paradigm was employed in which subjects were presented with random sequence of tones while they performed a discrimination task in visual modality with no response to the tone (passive task) or responded to an infrequently occurring target stimulus inserted into sequence of frequent standard and rare non-target stimuli (active task). Results show that the magnitude of the frontal P3 response is determined by the relative perceptual distinctiveness among stimuli. The amplitude of frontal component is larger for the stimuli more deviated from the standard in both passive and active tasks. In all cases however, a maximum over central or fronto-central scalp regions was demonstrated. Moreover, amplitude of this component was influenced by the strength of attentional focus – a significantly larger response was obtained in the active session than in its passive counterpart. The apparent parietal P3 responses were obtained only in the active condition. The amplitude of this component is larger for the target than the non-target across all electrode sites, but both demonstrated a parietal maxima. This findings suggest that generation of early frontal P3 could be related to alerting activity of frontal cortex irrespective of stimulus context, while generation of later parietal P3 is related to temporo-parietal network activated when neuronal model of perceived stimulation and attentional trace are comparing.

Key words: ERP, P3a, P3b, 3-stimulus paradigm, passive vs. active tasks, auditory modality

INTRODUCTION

The P3 is probably the most frequently studied component of the Event-Related Potentials (ERP). It has been widely applied in studies of cognitive dysfunction in clinical population as well as normal functioning in healthy subjects (Polich and Herbst 2000, Hruby and Marsalek 2003). There is general agreement that P3 provides a valuable tool for the systematic investigation of attentional and memory processes in the human brain. This positive component, with a peak latency of 300–800 ms, is commonly obtained in several versions of the oddball paradigm (Picton 1992, Polich and Kok 1995, Comerchero and Polich 1999). In this paradigm,

rare target stimuli are inserted in series of much more frequent standard stimuli of the same modality. The task given to the subject is usually to notice the presence of target stimulus and to react to it, typically by pressing a button, or just by mental counting. P3 responses with a similar topography can also be generated in a single stimulus task where a single target is randomly presented as in the oddball paradigm, but with the standard stimuli replaced by silence (Polich et al. 1994, Mertens and Polich 1997, Strüber and Polich 2002, Wronka et al. 2007). In the 3 stimulus variant of the oddball paradigm, an additional infrequent-non-target stimulus is inserted into a sequence of infrequent target and frequent standard stimuli (Katayama and Polich 1998, 1999). In contrast to this, the passive version of oddball task does not require reaction from the subject. In this case, subject's attention is usually directed away from the sequence of standard and devi-

ant tones toward another, moderately demanding task, usually in different modality (Näätänen 1990).

There is general consensus that P3 is not a unitary brain potential but represents the summation of activity from various widely distributed areas in the brain and a distinction can be made between several subcomponents which temporally overlap (Polich and Criado 2006). It is generally accepted that a distinction can be made between at least two subcomponents, namely the P3a and the classical P3 (or P3b). The P3a is a large, positive deflection with a fronto-central distribution and is typically elicited by novel or non-target stimuli inserted in a series of standard and target stimuli in a 3 stimulus oddball paradigm. This component has a relatively short peak latency (Courchesne et al. 1975, Friedman and Simpson 1994). A suggestion is that it reflects an alerting process in the frontal lobe while involuntary attention shifts to changes in the environment takes place (Yamaguchi and Knight 1991a). The P3a is sometimes referred to as the novelty P3 (Yamaguchi and Knight 1991a,b). However, it is still not clear if the P3a and 'novelty' P3 reflect exactly the same physiological and psychological process even if they share similar scalp topography (Courchesne et al. 1975, Squires et al. 1975).

The P3b (or classical P3) has a more posterior-parietal scalp distribution and a somewhat longer latency than P3a. There is broad evidence that this component could be regarded as reflecting target stimulus classification in tasks that require some form of action like a covert or overt response to stimuli (Donchin and Coles 1988, Kok 2001). Specifically, the P3b has been considered as indexing voluntary attention, such that its amplitude reflects the allocation of attentional resources (Kok 2001, Wronka et al. 2007), and its peak latency is considered to be related to stimulus evaluation time (Kutas et al. 1977). What also important is that, the distinction between P3a and P3b is evident for both auditory and visual modalities (Comerchero and Polich 1999, Katayama and Polich 1999). The P3b component seems to be elicited exclusively by target stimulus, the only stimulus in the sequence required obligatory response. In contrast to this, rare but non-target visual stimuli which could be easily recognized elicit a P3 with maximum over central-parietal areas (Courchesne 1978, Courchesne et al. 1978). Similarly, in the auditory modality, Pfefferbaum and colleagues (1980, 1984) found that an infrequently presented non-target tone inserted into the traditional oddball tone

sequence elicited a parietal P3 of smaller amplitude than the target P3. This component is sometimes referred to as a 'no-go' P3 since response to infrequent non-target is not required from the subject.

When taken together with the P3a subcomponent findings outlined above, it could be suggested that the P3 may be composed of at least few constituent potentials that reflects distinct information processing events. Thus, all the P3 subcomponents appears to vary in their locus of scalp distribution, magnitude and peak latency as a function of the stimulus context. There is no agreement for naming the P3 subcomponents elicited in a passive condition, physically novel stimuli, or rare non-target stimuli in three-stimulus oddball task, whereas a target P3 from the active tasks is consistently referred to as P3b. Näätänen (1990) has suggested that P3a could be considered as the reflection of the attentional switch produced from the mismatch between a presented stimulus and passively formed neuronal trace, whereas P3b reflects the match between the stimulus and voluntarily maintained attentional trace.

The purpose of the present study was to examine in more detail the basic characteristics of the P3 subcomponents elicited in the passive and active versions of the three-tone oddball paradigm. As it was outlined above, the three-stimulus oddball paradigm is a modification of the oddball task in which rare non-target stimuli are inserted into a sequence of rare target and frequent standard stimuli (active version) or two different rare stimuli are presented in addition to the sequence of more frequent standard stimulus (passive version). In its passive variant the three-stimulus paradigm gives the opportunity to verify the finding that the relative perceptual distinctiveness among stimuli significantly affects the amplitude of the early fontal P3a. The greater is the mismatch between the standard and rare stimuli (usually dubbed as deviant stimuli) the stronger the attentional switch and the larger is the P3a response to the presented deviant. At the same time, however, no specific reaction is required from the subject and thus, no evident P3b component would be expected in reaction to deviant stimuli exposition. The active variant of three-stimulus oddball task could also be utilize to elicit the P3a response (Katayama and Polich 1998, 1999, Comerchero and Polich 1999, Jeon and Polich 2001) which is not readily apparent in all individuals when traditional two-stimulus oddball is implemented (Polich 1988). If the P3a component elicited under passive and active conditions reflect similar

physiological processes, then its scalp distribution as well as the relative difference dependent on stimulus distinctiveness, will not differ significantly. However, studies in which characteristics of this component have been directly compared between passive and active condition are scarce (Bennington and Polich 1999, Jeon and Polich 2001). It could be also noticed that in most studies with three-stimulus tasks no differentiation were made between the early and late P3 (Katayama and Polich 1996a, 1996b, 1998, 1999, Comerchero and Polich 1999, Jeon and Polich 2001). Hence, so far it is not clear whether early frontal P3s obtained in passive and active condition reflect similar physiological processes. In the active three-stimulus paradigm an obvious P3 with parietal maximum should be obtained in response to both target and non-target stimuli. However, also in this case, it is not clear whether both differ in its scalp distribution and thus reflect activity of distinct brain generator.

Taken together, our experimental design allow a direct comparison of basic characteristics of both frontal and parietal P3 components measured in response to exactly the same set of auditory stimuli under passive and active conditions. We predict that if early frontal P3a components measured under passive and active tasks in our experiment will not differ significantly in their scalp topography then both reflect the same or a very similar physiological and psychological process. At the same time we expect differences in their amplitudes which are determined by the strength of attentional focus (Katayama and Polich 1999). Similarly, if the late parietal P3 components obtained in response to target and non-target stimuli in active task will not differ in their scalp distribution, despite the expected differences in its amplitude and latency, then both could be considered as the index of a similar set of processes.

In order to determine clearly the P3 subcomponents, difference waves were calculated by subtracting the standard stimulus ERP from both deviants' stimuli ERPs obtained in passive condition and from both target and non-target ERPs obtained in active condition.

METHODS

Subjects

Thirty healthy male and female students (M = 21.1 years; SD = 1.52 years) served as participants in the experiment. All of them were right-handed and had normal, or corrected to normal, vision, as well as normal hearing. They received course points for their participation and signed an informed consent. All participants, reported being free of neurological or psychiatric disorders. Due to excessive eye or muscle artefacts two subjects had to be excluded, thus the final group consisted of twenty eight subjects (20 females and 8 males).

Recording conditions

The EEG was recorded from 31 mono-polar locations (Fp1/Fp2, F3/F4, F7/F8, FT7/FT8, FC3/FC4, T7/T8, C3/C4, TP7/TP8, CP3/CP4, P7/P8, P3/P4, O1/O2, AFz, Fz, FCz, Cz, CPz, Pz, Oz) according to the 10–20 international electrode placement system. All the electrodes were placed on the scalp using an Electro-Cap and were referred to the C1 recording. The horizontal and vertical EOG were monitored by additional 4 electrodes, placed above and below the right eye and in the external canthi of both eyes. The EEG was amplified at a sampling rate of 1024 Hz using BioSemi ActiveOne system. Output data were subsequently transferred to and stored in a computer for analysis. The EEG data was off-line filtered with band pass 0.01–35 Hz (24 dB), and sampled for 1.0 s trial (100 ms prior to stimulus onset and 900 ms after stimulus onset) using BrainVision software. Finally, data were corrected for eye-movement artifacts (Gratton et al. 1983) and re-referenced to average montage.

Procedure

The entire experiments lasted about one hour, interrupted by a short break, and subjects were seated in a darkened sound-isolated, air-conditioned chamber. They were asked to relax and to restrict body movements and blinking as much as possible. Two separate sessions in the experiment were employed. In the first session the subjects were presented with random series of tones (consisting of standard, deviant 1 and deviant 2 tones with probabilities of 0.80, 0.10, and 0.10, respectively) while they performed visual task. In the visual task, random series of photographs of faces were presented and subjects were instructed to silently count the male or female faces (this instruction was counterbalanced across the subjects). They were also informed that there was no task associated with the auditory stimuli. In the second session the subjects were only

presented with random series of tones (consisting of standard, target and non-target tones with probabilities of 0.80, 0.10, and 0.10, respectively) and were asked to silently count the target tones and report the total number at the end of the session. The passive condition was introduced to each participant before they undertook the active condition. The fixed order of the tasks was used to avoid the carry-over effect possible when a set of stimuli attended in one condition should be ignored in the following condition.

Stimuli

Stimulus tones were presented with random ISI (1.25–2.0 s) through loudspeaker located in front of subject at 65 dB SPL (100 ms duration with 10-ms rise/fall time). The tone frequencies for each stimulus type and experimental condition are summarized in Table I.

The visual stimuli in passive condition were presented on a 19 inch monitor viewed from a distance of 1 m. Stimuli were centrally presented black and white photographs (10 × 15 cm) of 10 different individuals (5 women and 5 men) with neutral facial expression. Each visual stimulus was presented for 6 s with random ISI (4–8 s). The onset of visual stimuli was always simultaneous to the onset of standard auditory stimulus and these trials were excluded from analysis.

Data analyses

The P3 latencies and amplitudes were measured on difference waves, calculated by subtracting the average ERP elicited by the standard stimuli from that elicited by the deviant 1 (target) and deviant 2 (non-target) stimuli. As the focus of the present study was the basic characteristics of the P3 components elicited

in response to rare stimuli (deviant 1/target; deviant 2/non-target), only the P3s from these stimuli are reported. The components are defined as the largest positive-going peaks within a specific latency window: for the passive condition 200–350 ms and 350–700 ms for the early and late P3s, respectively, and for the active condition 250–400 ms and 400–700 ms for the early and late P3s, respectively. These windows were selected on the basis of visual inspection of grand averaged ERP obtained for each condition. Peak amplitude was calculated relative to the pre-stimulus baseline, and peak latency was measured from the time of stimulus onset.

Repeated-measures analyses of variance (ANOVA) were performed examining the effect of within-subjects factors of electrodes LOCATION (5 anterior-to-posterior locations), STIMULUS type (deviant 1/target vs. deviant 2/non-target), and CONDITION (passive vs. active) on P3 mean amplitude and latency. The effects of LOCATION were examined in orthogonal five-level repeated-measures sagittal factor and arranged such that the lateral (coronal) electrode arrays were nested under the anterior-to-posterior factor locations (F3-Fz-F4 vs. FC3-FCz-FC4 vs. C3-Cz-C4 vs. CP3-CPz-CP4 vs. P3-Pz-P4), which yielded two orthogonal electrode factors. This approach permits the direct assessment of interactions between the frontal-to-parietal topography distributions across lateral electrode with respect to the experimental independent variables. All analyses of variance employed Greenhouse-Geisser corrections to the degrees of freedom when appropriate, and only the corrected probability values are reported. The Bonferroni method was used for *post-hoc* comparisons, with a significance level of 0.05.

RESULTS

Task performance was virtually perfect for both conditions (<1% error rates for each condition).

Figure 1 presents the grand average ERPs from the standard, deviant 1, and deviant 2 stimuli for each electrode under passive condition. Figure 2 presents the grand average ERPs from the standard, target, and non-target stimuli for each electrode under active condition. Difference waves from passive condition obtained by subtracting ERP for standard tone from ERPs for both deviant 1 and deviant 2 stimuli is presented in Fig. 3. Similarly, difference waves from

Table I

Tone stimulus (probabilities) and frequencies (Hz) for each stimulus type and experimental condition

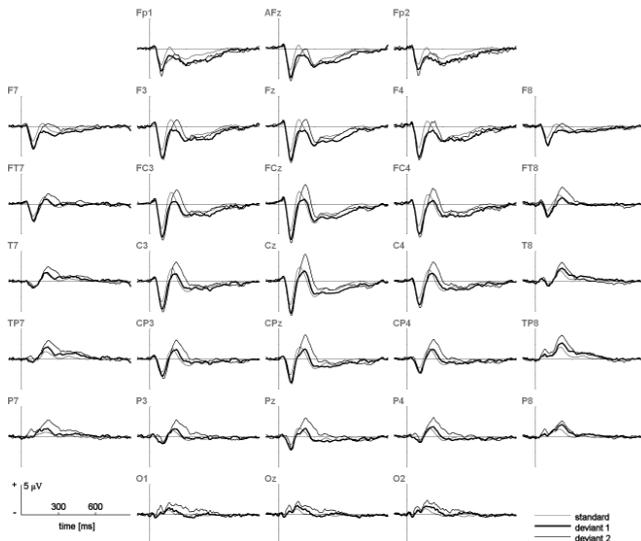| passive condition	active condition	frequencies
standard (0.80)	standard (0.80)	1 000 Hz
deviant 1 (0.10)	target (0.10)	1 100 Hz
deviant 2 (0.10)	non-target (0.10)	1 200 Hz

Fig. 1. Grand averaged ERP form passive condition for each stimulus type and recording site. Standard, deviant 1, and deviant 2 stimuli were presented with probabilities of 0.80, 0.10, and 0.10, respectively.

Fig. 3. Grand averaged difference waves form passive condition for each stimulus type and recording site. Thick black line represents deviant 1 minus standard difference, and thin black line represents deviant 2 minus standard difference.
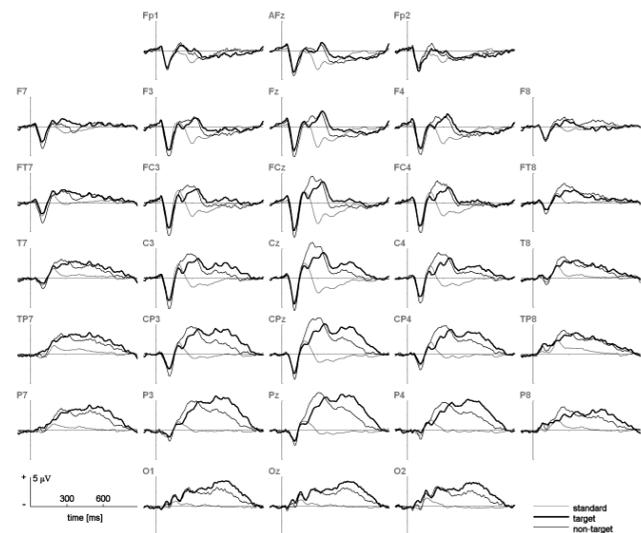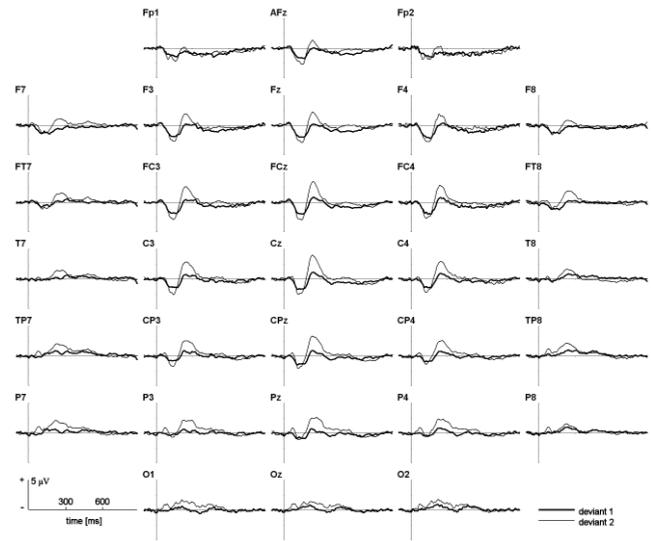

Fig. 2. Grand averaged ERP form active condition for each stimulus type and recording site. Standard, target, and non-target stimuli were presented with probabilities of 0.80, 0.10, and 0.10, respectively.
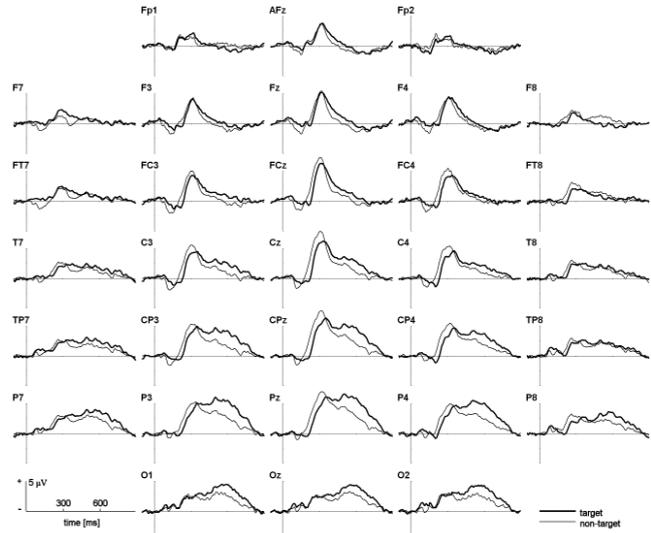

Fig. 4. Grand averaged difference waves form active condition for each stimulus type and recording site. Thick black line represents target minus standard difference, and thin black line represents non-target minus standard difference.

active task, acquired by subtracting standard stimulus ERP from ERPs for target and non-target tones, is represented in Fig. 4.

Early P3 amplitude

The mean P3 amplitudes from the passive condition (deviant 1 and deviant 2 stimuli) and from the active con-

dition (target and non-target stimuli) are illustrated in Fig. 5. The data were assessed initially with a three-factor (LOCATION × CONDITION × STIMULUS) ANOVA. The results of this analysis are summarized in Table II, in which only significant effects are presented. The amplitude of P3 component measured during active condition was significantly larger when compared to the P3 obtained in passive condition. On the other hand, significantly

Table II

Summary of the three-factor analysis of variance on the early and late P3 amplitudes

source (df)	Early P3 amplitude			Late P3 amplitude		
	F	P	ε	F	P	ε
L (4,108)	6.62	0.007	0.372	35.10	<0.001	0.319
S (1,27)	19.20	<0.001	-	1.25	-	-
C (1,27)	23.04	<0.001	-	23.31	<0.001	-
S × C (1,27)	-	-	-	13.19	0.001	-
L × S (4,108)	8.31	0.002	0.369	1.59	-	-
L × C (4,108)	-	-	-	28.07	<0.001	0.374
L × S × C (4,108)	4.10	0.031	0.405	1.28	-	-

larger P3 amplitude was observed in response to rare stimuli more physically deviated from standard stimulus (deviant 2 and non-target), in comparison to P3 elicited by deviant 1 or target stimuli. This effect was comparable for passive and active condition what is confirmed by insignificant STIMULUS × CONDITION interaction.

Because the three-way interaction was significant, separate two-factor (LOCATION × STIMULUS) analyses on passive and active conditions were performed. The main effect of stimulus type was still significant in both analyses ($F_{1,27}$=16.80, P<0.001 and $F_{1,27}$=9.74, P=0.004, for passive and active condition respectively). The amplitude of P3 recorded in response to deviant 2/non-target stimuli was found bigger in comparison to P3 obtained in response to deviant 1/target tones. This suggests that the magnitude of P3 response is related to the size of rare stimuli deviation from standard tone. Similarly, the main effect of location was significant in both analyses either ($F_{4,108}$=6.3,1 P=0.010, ε=0.340 and $F_{4,108}$=4.05, P=0.031, ε=0.413, for passive and active condition respectively). For the passive condition, the P3 of maximal amplitude was recorded at the Cz electrode for both deviant stimuli. In contrast to this, for the active condition maximum at Cz was obtained for the non-target stimuli whereas the P3 elicited by the target stimulus peaked maximally at more anterior FCz electrode. This leads to a significant interaction of LOCATION × STIMULUS factors for active ($F_{4,108}$=11.37, P<0.001, ε=0.437) but not or passive condition.

Late P3 amplitude

The mean P3 amplitudes from the passive condition (deviant 1 and deviant 2 stimuli) and from the active condition (target and non-target stimuli) are illustrated in Fig. 5. The data were assessed initially with a three-factor (LOCATION × CONDITION × STIMULUS) ANOVA. The results of this analysis are summarized in Table II, in which only significant effects are presented.

The amplitude of P3 component measured during active condition was significantly larger in comparison to the P3 recorded in passive condition. Main effect of STIMULUS was not significant. However, at the same time, significant STIMULUS × CONDITION interaction was found. The P3 amplitude in response deviant 2 stimuli under passive condition was larger than P3 amplitude obtained for deviant 1 tones. An opposite difference was observed in the active condition where P3 elicited by target tones was larger in comparison to P3 elicited by non-target stimuli as it is indicated in Fig. 5. Finally, no significant result was found when the three-way interaction (LOCATION × CONDITION × STIMULUS) was examined.

When an analysis of the effect of LOCATION was separately done for each condition, a significant results were found for both the passive ($F_{4,108}$=7.77, P=0.002, ε=0.432), and for the active task ($F_{4,108}$=36.20, P<0.001, ε=0.329). This suggests that the amplitude of
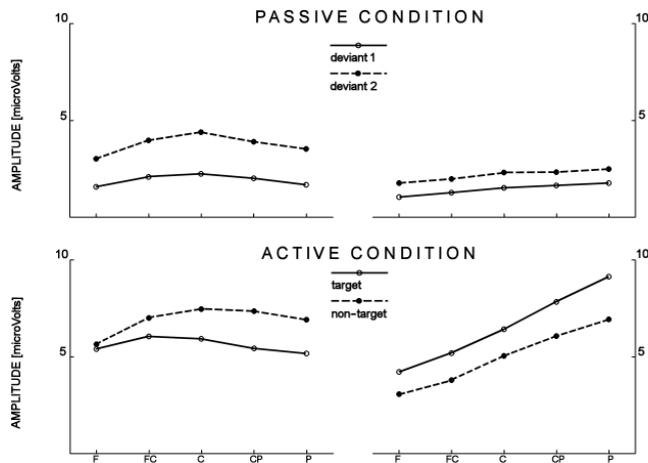
Fig. 5. Mean amplitude of early P3 (left panel) and late P3 (right panel) from passive (deviant 1 and deviant 2 stimuli) and active (target and non-target stimuli) as a function of electrode locations. (F) frontal; (FC) fronto-central; (C) central; (CP) centro-parietal; (P) parietal.
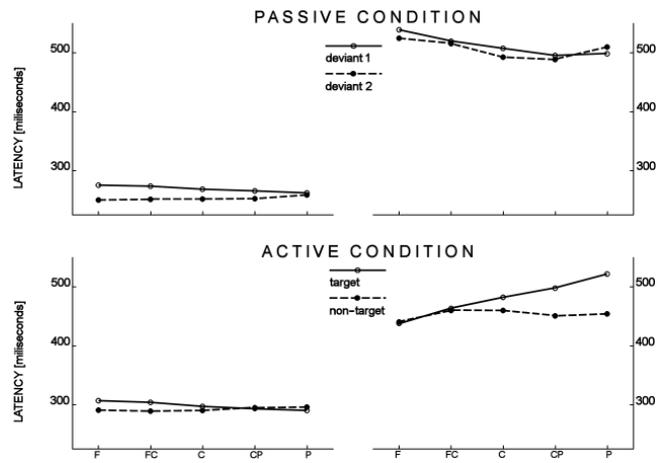

Fig. 6. Mean latency time of early P3 (left panel) and late P3 (right panel) from passive (deviant 1 and deviant 2 stimuli) and active (target and non-target stimuli) as a function of electrode locations. (F) frontal; (FC) fronto-central; (C) central; (CP) centro-parietal; (P) parietal.

the late P3 component, obtained in both conditions and for both types of rare stimuli, increased from frontal to parietal locations. This suggestion was additionally confirmed by non-significant interaction STIMULUS × LOCATION for both passive and active condition. Finally, an analysis of the effect of STIMULUS separately conducted for each condition delivered a significant result but only for P3 obtained in active condition ($F_{1,27}$=10.32, P=0.003), but not for its passive counterparts.

Early P3 latency

The mean P3 latencies from the passive condition (deviant 1 and deviant 2 stimuli) and from the active condition (target and non-target stimuli) are illustrated in Fig. 6. The data were assessed initially with a three-factor (LOCATION × CONDITION × STIMULUS) ANOVA. The results of this analysis are summarized in Table III, in which only significant effects are presented. Highly significant main effect of CONDITION

Table III

Summary of the three-factor analysis of variance on the early and late P3 latencies

source (df)	Early P3 amplitude			Late P3 amplitude		
	F	P	ε	F	P	ε
L (4,108)	-	-	-	-	-	-
S (1,27)	11.48	0.002	-	-	-	-
C (1,27)	49.86	<0.001	-	5.69	0.024	-
S × C (1,27)	-	-	-	-	-	-
L × S (4,108)	9.71	<0.001	0.622	-	-	-
L × C (4,108)	-	-	-	12.92	<0.001	0.619
L × S × C (4,108)	-	-	-	5.40	0.002	0.730

was found indicating that latencies of early P3 components measured in passive condition were shorter than of the equivalent peaks in active condition. Moreover, latency of P3 response to deviant 2 stimulus was shorter than latency of P3 component measured as a response to deviant 1 stimulus. Comparable effect was observed also for active condition, where latency of P3 component elicited by non-target tone was shorter than latency of target P3. This leads to significant main effect of STIMULUS. However, strength of this effect was varied between anterior and posterior location, which resulted in a significant interaction of STIMULUS × LOCATION factors. No other effects or interaction were significant.

When the interaction of STIMULUS × LOCATION was inspected separately for each condition, a significant results were found for both the passive ($F_{4,108}$=4.16, P=0.011, ε=0.551), and for the active task ($F_{4,108}$=5.40, P=0.003, ε=0.656), what confirmed our previous conclusion. At the same time, significant effect of STIMULUS was obtained for passive condition ($F_{1,27}$=6.81, P=0.015). In case of similar analysis performed for active condition this effect did not reach the level of significance ($F_{1,27}$=2.93, P=0.098). No other effects were significant.

Late P3 latency

The mean P3 latencies from the passive condition (deviant 1 and deviant 2 stimuli) and from the active condition (target and non-target stimuli) are illustrated in Fig. 6. The data were assessed initially with a three-factor (LOCATION × CONDITION × STIMULUS) ANOVA. The results of this analysis are summarized in Table III, in which only significant effects are presented. Significant main effect of CONDITION was found indicating that latency of P3 component measured in active condition was shorter than the latency of P3 peak in passive condition. This difference was especially clear for anterior location, what was confirmed by significant interaction of LOCATION × CONDITION. At the same time, the three-way interaction (LOCATION × STIMULUS × CONDITION) was also significant.

When the separate two-factor (LOCATION × STIMULUS) analyses on passive and active conditions were performed for each condition, a significant result was found only for the active condition ($F_{4,108}$=4.16, P=0.013, ε=0.626). Simultaneously, inspection of effect of LOCATION delivered significant results for both passive ($F_{4,108}$=3.78, P=0.025, ε=0.548) and active condition ($F_{4,108}$=7.74, P=0.001, ε=0.572). The weak effect of STIMULUS was observed only in active condition and did not reach the level of significance ($F_{1,27}$=3.12, P=0.089).

DISCUSSION

The differential amplitudes of the late parietal P3 measured in response to both nonstandard in the passive and active session confirmed the successful manipulation of the task instruction. When participant's attention was engaged in the visual task and no specific reaction to auditory stimuli was required, the ERP measured in response to both deviant stimuli consisted of small deflection observed in P3 time window with a maximum over the parietal location. On the contrary, when voluntary attention resources were provoked by experimental instruction to discrimination among auditory stimuli evident P3 deflections were obtained for both target and non-target stimuli. In both cases, parietal maxima were observed. It is also reasonable to conclude that the target and non-target stimulus in the auditory modality elicited a P3 component with the same neural generator. This finding extend previous results of Katayama and Polich (1999), in which normalized amplitude analysis indicated that the topography of the P3 component measured in auditory and visual three-stimulus tasks was independent of stimulus modality as well as stimulus type (i.e. target and non-target). This outcome supports also the previous finding that the target P3 elicited in the three-tone paradigm is essentially identical to the target P3 from a two-tone oddball or a single stimulus auditory paradigm (Polich et al. 1994, Katayama and Polich 1996a, Mertens and Polich 1997, Strüber and Polich 2002, Wronka et al. 2007). The magnitude of late parietal P3 response to relevant target stimulus was found larger than in case of non-target tone in our study. This result is highly consistent with many reports using three-stimulus oddball paradigm (Polich 1986, 1987, Katayama and Polich 1996a, 1996b, 1999, Comerchero and Polich 1999). However, contrary to some previous studies (Pfefferbaum et al. 1980) latency of parietal P3 deflection elicited by target tone was longer in comparison to the latency of non-target P3. This inconsistency could be partially explained by the fact that the relationship between latencies of target and non-target

P3 was found to be modulated by the stimulus context. Particularly, Katayama and Polich (1998) manipulated the size of deviation between the standard and non-standard auditory stimuli. They found that the larger is the size of physical difference between the frequent and rare tones, the longer is the latency of particular P3 deflection. Thus, when discrimination between standard and target stimuli become harder than differentiation between standard and non-target, then target P3 appear later than non-target P3 and *vice versa*. Similar results for auditory and visual modality were also reported by Comerchero and Polich (1999). Thus, it is reasonable to accept that component described here as the late parietal P3 is analogous to P3b in the literature.

Our manipulation of task instruction influenced also the magnitude of early frontal P3 response. The amplitude of this component in the active condition was found larger overall than in passive session. This result is in close agreement with previous studies (Katayama and Polich 1999) were magnitude of frontal P3 response was suggested to be modulated by the strength of attentional focus. Specifically, a more difficult discrimination between targets and standards evokes a larger frontal P3 response to rare non-targets. These results demonstrate that voluntary attention could modulate the involuntary response to irrelevant but unexpected events. Similar effects were also reported for the visual modality (Comerchero and Polich 1999) and auditory single stimulus task (Wronka et al. 2007). In addition, the latencies of early frontal P3 components measured in our passive condition were shorter than the latencies of equivalent peaks in active condition. The possible explanation for this effect is that larger P3 response in active condition develop longer than the less pronounced deflection in passive condition.

The magnitude of early frontal P3 response was also consistently related to the size of stimulus deviation from standard. In the passive condition, the deviant 2 stimuli which is more different from the standard, elicited a larger P3 component than the equally probable deviant 1 stimuli. Similarly, in the active condition the P3 response to non-target stimuli was greater than the response to target stimuli of the same frequency. This effect is also compatible with the previous reports (Comerchero and Polich 1999, Katayama and Polich 1998, 1999). Moreover, it should be noticed that frontal P3 amplitude dependence on stimulus physical devia-tion was observed without any difference in probability of occurrence under both passive and active condition. This supports the thesis that stimulus similarity or its discrimination difficulty importantly contribute to early frontal P3 generation (Comerchero and Polich 1999).

At the same time, scalp distribution of frontal P3 component obtained in our experiment is consistent with reported in previous studies (Courchesne et al. 1975, Yamaguchi and Knight 1991a,b, Friedman and Simpson 1994). Similar vertex maxima for this component were observed in case of both nonstandard stimuli in passive condition as well as for non-target tone in active condition. This could be interpreted as reflecting the activity of the same neuronal generator located within frontal lobe (Polich and Criado 2006). However, maximum amplitude of P3 response elicited in our study by target stimulus in active condition was found slightly more anterior. The different scalp distribution of P3 response to target tone could be connected with the fact that for this type of events temporary representation in working memory was necessary. Single-cell recordings in animals and neuroimaging studies in humans, provide evidence that the prefrontal cortex is important for working memory functions (D'Esposito et al. 2000, Passingham and Sakai 2004). Thus, holding temporary representation of relevant event could therefore alter initial attention reallocation reflected by early frontal P3 component. This suggests that P3 neural generators were differentially engaged as a function of stimulus context demands. Accordingly, it seems acceptable to state that early frontal P3 component from our study is analogous to P3a in the literature.

CONCLUSIONS

In conclusion, results of our experiment support the thesis that early frontal and late parietal P3 components of the ERP reflect two different sets of physiological and psychological processes. The frontal P3 could be related to early stages of initial attention engagement when distinct sensory information is gathered. Comparable basic characteristics of early frontal P3 responses measured in active and passive condition let us suggest that they reflected activity of very similar neural generator located within frontal cortex (Baudena et al. 1995). The characteristic of this activity depends on context within which perceptual

changes reflecting unexpected event in environment take place. The larger the mismatch is between presented stimulus and passively formed neuronal trace, the more intense is the involuntary attentional switch toward the new event and the more pronounced is its electrophysiological correlate – P3 component (Näätänen 1990). In addition, this initial attention reallocation could be facilitated when subject voluntary direct their attention toward the ongoing perceptual events. The results obtained in our study also suggests that late parietal P3 generation is almost exclusively joint with the matching between the neuronal model of perceived stimulus and voluntarily maintained attentional trace of relevant event (Näätänen 1990). The more advanced this process is, the greater is the P3 amplitude generated probably within posterior brain areas (Halgren et al. 1995a,b). Although the neural loci for both early and late P3s generation are not yet completely clear there is growing body of evidence that interaction between frontal lobe and hippocampal/temporal-parietal areas are the most likely.

REFERENCES

Baudena P, Halgren E, Heit G, Clarke J (1995) Intracerebral potentials to rare target and distractor auditory and visual stimuli. III. Frontal cortex. Electroencephalogr Clin Neurophysiol 94: 251–264.

Bennington JY, Polich J (2001) Comparison of P300 from passive and active tasks for auditory and visual stimuli. Int J Psychophysiol 34: 171–177.

Comerchero MD, Polich J (1999) P3a and P3b from typical auditory and visual stimuli. Clin Neurophysiol 110: 24–30.

Courchesne E, Hillyard SA, Galambos R (1975) Stimulus novelty, task relevance and the visual evoked potential in man. Electroenceph Clin Neurophysiol 39: 131–143.

Courchesne E (1978) Changes in P3 waves with event repetition: Longterm effects on scalp distribution and amplitude. Electroenceph Clin Neurophysiol 45: 754–766.

Courchesne E, Courchesne RY, Hillyard SA (1978) The effect of stimulus deviation on P3 waves to easily recognized stimuli. Neuropsychologia 16: 189–199.

D'Esposito M, Postle BR, Rypma B (2000) Prefrontal cortical contributions to working memory: evidence from event-related fMRI studies. Exp Brain Res 133: 3–11.

Donchin E, Coles MGH (1988) Is the P300 component a manifestation of context updating. Behav Brain Sci 11: 357–374.

Friedman D, Simpson GV (1994) ERP amplitude and scalp distribution to target and novel events: Effects of temporal order in young, middle-aged and older adults. Cogn Brain Res 2: 49–63.

Gratton G, Coles MGH, Donchin E (1983) A new method for off-line removal of ocular artifact. Electroenceph Clin Neurophysiol 55: 468–484.

Halgren E, Baudena P, Clarke J, Heit G, Liegeois C, Chauvel P, Musolino A (1995a) Intracerebral potentials to rare target and distractor auditory and visual stimuli. I. Superior temporal plane and parietal lobe. Electroenceph Clin Neurophysiol 94: 191–220.

Halgren E, Baudena P, Clarke J, Heit G, Marinkovic K, Devaux B, Vignal, J-P, Biraben A (1995b) Intracerebral potentials to rare target and distractor auditory and visual stimuli. II. Medial, lateral and posterior temporal lobe. Electroenceph Clin Neurophysiol 94: 229–250.

Hruby T, Marsalek P (2003) Event-related potentials – the P3 wave. Acta Neurobiol Exp (Wars) 63: 55–63.

Jeon Y, Polich J (2001) P3a from a passive visual stimulus task. Clin Neurophysiol 112: 2202–2208.

Katayama J, Polich J (1996a) P300 from one-, two-, and three-stimulus auditory paradigms. Int J Psychophysiol 23: 33–40.

Katayama J, Polich J (1996b) P300, probability, and the three-tone paradigm. Electroenceph Clin Neurophysiol 100: 555–562.

Katayama J, Polich J (1998) Stimulus context determines P3a and P3b. Psychophysiology 35: 23–33.

Katayama J, Polich J (1999) Auditory and visual P300 topography from a 3 stimulus paradigm. Clin Neurophysiol 110: 463–468.

Kok A (2001) On the utility of P3 amplitude as a measure of processing capacity. Psychophysiology 38: 557–577.

Kutas M, McCarthy G, Donchin E (1977) Augmenting mental chronometry: The P300 as a measure of stimulus evaluation time. Science 197: 792–795.

Näätänen R (1990) The role of attention in auditory information processing as revealed by event-related potentials and other brain measures of cognitive function. Behav Brain Sci 13: 201–287.

Mertens R, Polich J (1997) P300 from a single-stimulus paradigm: passive versus active tasks and stimulus modality. Electroenceph Clin Neurophysiol 104: 488–497.

Passingham D, Sakai K (2004) The prefrontal cortex and working memory: physiology and brain imaging. Curr Opin Neurobiol 14: 163–168.

Pfefferbaum A, Ford JM, Roth WT, Kopell BS (1980) Age related changes in auditory event-related potentials. Electroenceph Clin Neurophysiol 49: 266–276.

Pfefferbaum A, Ford JM, Wenegrat BG, Roth WT, Kopell BS (1984) Clinical application of the P3 component of event-related potentials. I. Normal aging. Electroenceph Clin Neurophysiol 59: 85–103.

Picton TW (1992) The P300 wave of the human event-related potential. J Clin Neurophysiol 9: 456–479.

Polich J (1986) Attention, probability, and task demands as determinants of P300 latency from auditory stimuli. Electroenceph Clin Neurophysiol 63: 251–259.

Polich J (1987) Task difficulty, probability, and inter-stimulus interval as determinants of P300 from auditory stimuli. Electroenceph Clin Neurophysiol 68: 311–320.

Polich J (1988) Bifurcated P300 peaks: P3a and P3b revisited? J Clin Neurophysiol 5: 287–294.

Polich J, Eischen SE, Collins GE (1994) P300 from a single auditory stimulus. Electroenceph Clin Neurophysiol 92: 253–261.

Polich J, Kok A (1995) Cognitive and biological determinants of P300: An integrative review. Biol Psychol 41: 103–146.

Polich J (1998) P300 clinical utility and control of variability. J Clin Neurophysiol 15: 14–33.

Polich J, Herbst KL (2000) P300 as a clinical assay: rationale, evaluation, and findings. Int J Psychophysiol 38: 3–19.

Polich J, Criado JR (2006) Neuropsychology and neuropharmacology of P3a and P3b. Int J Psychophysiol 60: 172–185.

Squires NK, Squires KC, Hillyard SA (1975) Two varieties of long-latency positive waves evoked by unpredictable auditory stimuli in man. Electroenceph Clin Neurophysiol 38: 387–401.

Strüber D, Polich J (2002) P300 and slow wave from oddball and single-stimulus visual tasks: inter-stimulus interval effects. Int J Psychophysiol 45: 187–196.

Wronka E, Kuniecki M, Kaiser J, Coenen AML (2007) The P3 produced by auditory stimuli presented in a passive and active condition: modulation by visual stimuli. Acta Neurobiol Exp (Wars) 67: 155–164.

Yamaguchi S, Knight RT (1991a) P300 generation by novel somatosensory stimuli. Electroenceph Clin Neurophysiol 78: 50–55.

Yamaguchi S, Knight RT (1991b) Age effects on the P300 to novel somatosensory stimuli. Electroenceph Clin Neurophysiol 78: 297–301.