
The P3 produced by auditory stimuli presented in a passive and active condition: Modulation by visual stimuli

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Abstract. The aim of this study was to investigate how the processing of auditory stimuli is affected by the simultaneous presentation of visual stimuli. This was approached in an active and passive condition, during which a P3 was elicited in the human EEG by single auditory stimuli. Subjects were presented tones, either alone or accompanied by the simultaneous exposition of pictures. There were two different sessions. In the first, the presented tones demanded no further cognitive activity from the subjects (passive or ‘ignore’ session), while in the second session subjects were instructed to count the tones (active or ‘count’ session). The central question was whether inter-modal influences of visual stimulation in the active condition would modulate the auditory P3 in the same way as in the passive condition. Brain responses in the ignore session revealed only a small P3-like component over the parietal and frontal cortex, however, when the auditory stimuli co-occurred with the visual stimuli, an increased frontal activity in the window of 300–500 ms was observed. This could be interpreted as the reflection of a more intensive involuntary attention shift, provoked by the preceding visual stimulation. Moreover, it was found that cognitive load caused by the count instruction, resulted in an evident P3, with maximal amplitude over parietal locations. This effect was smaller when auditory stimuli were presented on the visual background. These findings might support the thesis that available resources were assigned to the analysis of visual stimulus, and thus were not available to analyze the subsequent auditory stimuli. This reduction in allocation of resources for attention was restricted to the active condition only, when the matching of a template with incoming information results in a distinct P3 component. It is discussed whether the putative source of this effect is a change in the activity of the frontal cortex.

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INTRODUCTION

There is common agreement that attention is a complex phenomenon influencing perceptual processing and enabling perceptual awareness of attended events. There is also general consensus that attention could be divided into at least two different forms. Involuntary attention, also described as exogenous or orienting attention, is closely related to changes in brain processes evoked by the occurrence of unexpected events in the surrounding. These changes lead to switches in attention and are noted as the 'bottom-up' processes in nature. On the other hand, attention is also related to the voluntary detection of relevant objects which was previously related to working memory. This type of attention, sometimes called endogenous or executive attention, utilizes the process of top-down modulation and is more closely related to conscious processing and controlled reactions. Voluntary forms of attention are also closely linked to selective functions of attention (Posner 1995).

Event-related potentials (ERP) provide a valuable index of covert sensory and cognitive processing in humans. Probably no other ERP component is considered to be closer related to attention than P3. The P3 component of the ERP, with a peak latency of 300–500 ms, is commonly obtained in an oddball paradigm (Picton 1992), but P3 responses with a similar topography can also be generated in a single stimulus task (Mertens and Polich 1997, Strüber and Polich 2002). There is a general agreement 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 two sub-components which temporally overlap, namely P3a and P3b (Hruby and Marsalek 2003). P3a is a large, positive deflection with a fronto-central distribution that is elicited by novel and non-target stimuli and that mainly reflects an alerting process in the frontal lobe while involuntary attention shifts to changes in the environment takes place (Yamaguchi and Knight 1991a). P3a is easily obtainable in response to auditory or visual deviant non-target events in an oddball paradigm (Katayama and Polich 1998, 1999). In contrast, P3b has a more posterior-parietal scalp distribution and a somewhat longer latency than P3a. There is broad evidence that P3b could be regarded as reflecting target stimulus classification or evaluation in tasks that require some form of action like a covert or overt

response to meaningful stimuli when voluntary attention is engaged (Donchin and Coles 1988, Kok 2001, Polich 1998). The distinction in P3a and P3b is evident for both auditory and visual modalities, although the P3 elicited by auditory stimuli differs from the P3 evoked by visual stimuli in some qualities. For example, the amplitude of the visual P3 is higher than the auditory P3 (Gonsalvez and Polich 2002, Katayama and Polich 1999).

The relationship between involuntary and voluntary attention, as indexed by P3a and P3b subcomponents, could be studied in both auditory and visual modalities. For example, Katayama and Polich (1999) found that amplitude of auditory P3a is determined by the strength of attentional focus. A more difficult discrimination between targets and standards evokes a larger P3a response to rare non-targets. These results demonstrate that voluntary attention could modulate the involuntary response to irrelevant but unexpected events. A similar effect was also reported for the visual modality (Comerchero and Polich 1999). However, it is not clear whether the observed effects are modality specific, despite their similarities, or whether these effects reflect an engagement of supra-modal attention mechanisms. Results from cross-modal spatial attention studies suggest that directing attention to a relevant modality modulate early modality-specific ERP components not only for that modality, but also for currently irrelevant modalities. For example, the initial modality specific components of the visual ERP are typically larger for stimuli at voluntarily attended locations than for stimuli at unattended locations (Luck and Girelli 2000). Similarly, auditory stimuli that appear at voluntarily attended locations evoke a larger negativity in the 60–200 ms range over the fronto-central scalp than sounds that appear at unattended locations (Näätänen 1990, Teder et al. 1993). These effects are commonly interpreted as evidence for attention based facilitation of perceptual processing. A similar effect of attention could also be observed over modalities. It was found that selective attention across modalities also influences early stages of sensory processing. Specifically, auditory stimuli that appear at voluntarily attended locations evoke enlarged early negativities (100–200 ms), even when viewers only respond to visual stimuli that appear at the attended location and ignore auditory stimuli irrespective of their origin in space (Eimer and Schröger 1998, Eimer et al. 2004, Hillyard et al. 1984, Teder-

Sälejärvi et al. 1999). Similar cross-modal effects take place for visual stimuli when the viewer voluntarily attends to sounds at a particular location (Eimer and Schröger 1998, Eimer et al. 2004, Teder-Sälejärvi et al. 1999). These results could suggest that the brain mechanisms that mediate spatial shifts of attention to auditory, visual, and tactile stimuli may be supramodal or at least tightly linked.

The open question is, however, whether cross-modal influence could be observed when stimuli in different modalities are not separated in space. Moreover, the question could be raised whether the cross-modal interaction could be visible not only at an initial stage of stimulus sensory encoding, but also at a later stage, when voluntarily attention is involved in conscious classification of the stimulation. The issue touched in the present paper is the nature of the interaction between two stimulus modalities: the visual and the auditory modality.

A similar issue was previously approached by Schupp and coauthors (1997). They showed that the amplitude of P3 response to white noise presented in parallel with visual stimuli depends on the pictorial content. They suggested that pictures evoking an emotional response, demanded more attentional resources in comparison to emotionally irrelevant pictures. They found that the more resources the visual stimuli consumed, the greater was the reduction of the P3 amplitude evoked by simultaneously presented auditory stimuli. Cuthbert and colleagues (1998) also found a smaller P3 elicited by auditory stimuli when simultaneously affective visual stimuli were presented when compared to P3 obtained in response to the same sounds but exposed concurrently with a neutral picture. This effect was comparable under attended as well as under unattended conditions. Oray and others (2002) reported a reduced auditory P3 amplitude when recorded in response to tone bursts paired with a visual stimulus. They suggested that involuntary attention to visual stimuli might suppress late cognitive processing of auditory events. These results are also consistent with findings that processing of irrelevant visual probe stimuli is suppressed when its exposition takes place shortly after presentation of visual target stimuli in oddball task, but not when the probe was preceded by frequent standard stimulus (Michalski 2001, Milner and Michalski 2003).

In all studies the visual and auditory stimuli were presented with a close temporal proximity and only

high intensity noise-bursts were tested (Oray et al. 2002). Furthermore, the P3 was evoked only with two different forms of parallel visual stimulation (Cuthbert et al. 1998, Schupp et al. 1997). Hence, so far it is not completely clear whether simultaneous exposure to innocuous visual stimuli influences the processing of auditory stimuli. Also the question of whether P3 amplitude is determined by the degree of inter-modal influence, cannot be unequivocally answered. Moreover, another unanswered question is whether in a passive condition, when only a small P3 is expected, a suppression of resources is likely. Thus, the aim of the present study was to examine the effects of a parallel presentation of innocuous, task-irrelevant, visual stimuli on an auditory ERP response. In order to clear up these questions, auditory stimuli were presented alone or accompanied with visual stimuli. To maximize the probability of inducing two distinct forms of cognitive activity, the experiment was divided into two sessions. In the first session, the subjects were instructed to passively perceive auditory events while simultaneously watching visual material or not, whereas in the second session participants were instructed to silently count the tones, in order to pay specific attention to the auditory stimuli, again while watching visual stimuli or not.

It was predicted that ERP responses obtained in the two sessions, would differ in the amplitude of the auditory P3. In the active (count) condition, a positive component with a latency of 300–500 ms was expected, but not in the passive (ignore) condition. Moreover, the active condition was designed to facilitate attentional resource allocations and, subsequently, to engage working memory. The positive component, expected in the active condition alone, was thought to have a maximum over parietal locations. Moreover, tones presented simultaneously with visual stimuli in the active condition, were thought to elicit a reduced parietal P3 component. This expectation was based on the view that attentional demands necessary for the processing of visual stimuli should result in a reduction of the available resources for the auditory modality, and might effectively weaken processing of this auditory information. However, in the passive condition only a small P3 was expected, implying that a main effect of the visual stimuli on the processing of the tones was not predicted, especially not on the parietal location.

METHODS

Forty two healthy male and female students, with an age range of 19–25 years ($M = 21.7$; $SD = 1.57$) took part in the experiment. Participants, reporting no medical or psychological problems, were right-handed and had normal, or corrected to normal, vision, as well as normal hearing. All of them received course points for their participation and signed an informed consent. Due to excessive eye or muscle artifacts ten subjects had to be excluded, thus the final group consisted of thirty-two subjects (22 females and 10 males).

The EEG was recorded from 3 mono-polar locations (Fz, Cz, Pz), 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 left mastoid recording. The electrode placed on the forehead served as a ground electrode. Electrode impedance was always less than $5\text{ k}\Omega$. The horizontal and vertical EOG were monitored by 4 electrodes, placed above and below the right eye and in the external canthi of both eyes. The electrical signals were sampled at a rate of 256 Hz with a time constant 10 s (equivalent of high pass filter 0.016 Hz), low pass filtered 30 Hz, and amplified 10000. Output data were subsequently transferred to and stored in a computer for analysis. The EEG was off-line sampled for 0.7 s trial (100 ms prior to stimulus onset and 600 ms after stimulus onset). Trials with EOG or EEG activity exceeding $50\text{ }\mu\text{V}$ were rejected and remaining data were corrected for eye-movement artifacts using BrainVision software (Gratton et al. 1983). The P3 component was defined as the positive-going peak with the highest amplitude occurring within 300–500 ms after onset of stimulus presentation. Peak amplitude was calculated relative to the pre-stimulus baseline, and peak latency was measured from the time of stimulus onset.

The entire experiments lasted about one hour, interrupted by a short break. 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. The experiment consisted of two separate sessions. In the first session the subjects were asked to passively perceive the tones and were informed that there was no task associated with the stimuli ('ignore' session), while in the second session the subjects were asked to silently count the tones and report the total number at the end of the session ('count' session). The sequence of stimuli presented was pseudo-

random, and was identical for each participant and for each session. This sequence consisted of 45 tones presented without visual stimulation (A condition) and 45 tones presented together with visual stimuli (VA condition). Tones had a frequency of 1 kHz and a duration of 100 ms with 10 ms rise/fall time (62 dB) and were presented through loudspeakers located behind the chair of the subject. Visual stimuli were back-projected on a screen located two meters from the subject. Visual stimuli consisted of slides with black neutral geometric figures on a grey background. When tones were presented during the exposition of a visual stimulus, the interval between slide onset and tone onset varied between 3.5 and 5 seconds. Each slide was presented for six seconds. Inter-trial interval (ITI) varied from 1 to 2 seconds.

Repeated-measures analyses of variance (ANOVA) were performed examining the effect of within-subjects factors of electrode LOCATION along the sagittal plane (Fz, Cz, Pz), stimuli presentation CONDITION (auditory vs. visual + auditory; A vs. VA), and SESSION (ignore vs. count) on P3 amplitude and latency. The effects of location were examined in orthogonal three-level repeated-measures location factor, while a Greenhouse-Geisser correction was applied when appropriate. Only the corrected values of P are reported.

RESULTS

Amplitudes of auditory P3

Figure 1 shows the grand average ERP elicited by tones presented alone and presented on the visual background in both the ignore and count sessions. The P3 component measured during the ignore session was clearly visible only on the frontal site, while in other cases this was less evident. In the count session, apparent P3 deflections were observed for each location and their amplitudes were significantly larger in comparison to the P3 amplitude obtained in the ignore session (main effect of SESSION factor: $F_{1,31}=72.75$, $P<0.0001$).

The analysis performed for the count session showed that P3 has a typical topography with its maximum over parietal locations ($F_{2,62}=76.63$, $P<0.0001$, $\epsilon=0.933$), as indicated in Fig. 2. The parietal maximum for P3 was also evident when the analysis was separately done for the tones alone ($F_{2,62}=70.76$, $P<0.0001$, $\epsilon=0.962$), and as well as for tones occurring on the

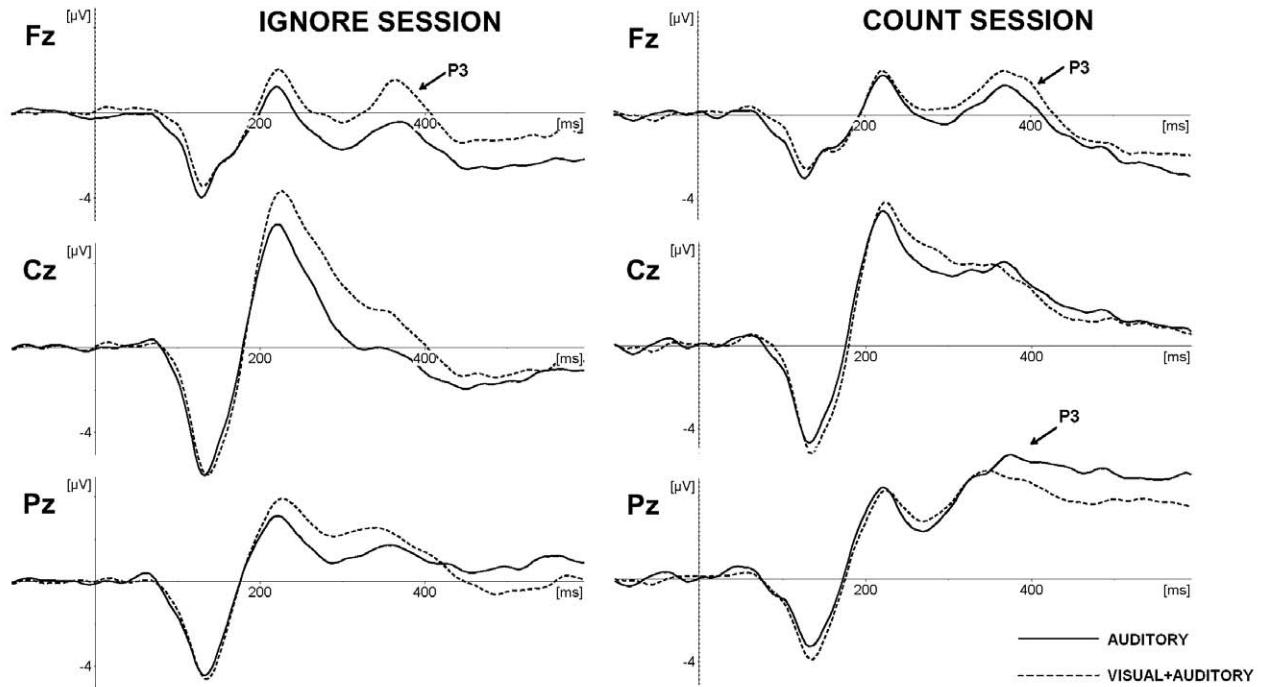


Fig. 1. Grand average ERP in response to tones recorded in ignore (left panel) and count (right panel) sessions. Solid lines indicate responses in auditory condition and dashed line indicate responses to visual + auditory condition.

visual background ($F_{2,62}=44.94$, $P<0.0001$, $\varepsilon=0.935$). On the other hand, when the P3 amplitude in the ignore session was inspected, significant effect of LOCATION was also found ($F_{2,62}=23.74$, $P<0.0001$, $\varepsilon=0.934$). A progressive increase of P3 amplitude was observed when the auditory and visual-auditory conditions in the ignore session were separately examined

($F_{2,62}=32.37$, $P<0.0001$, $\varepsilon=0.802$, and $F_{2,62}=5.78$, $P=0.014$, $\varepsilon=0.651$, respectively). This suggests that the amplitude of the P3 component, obtained in both conditions and in both sessions, increased from frontal to parietal locations. However, this change was more steep for P3 measured in the count session than for its ignore counterpart, which resulted in a significant

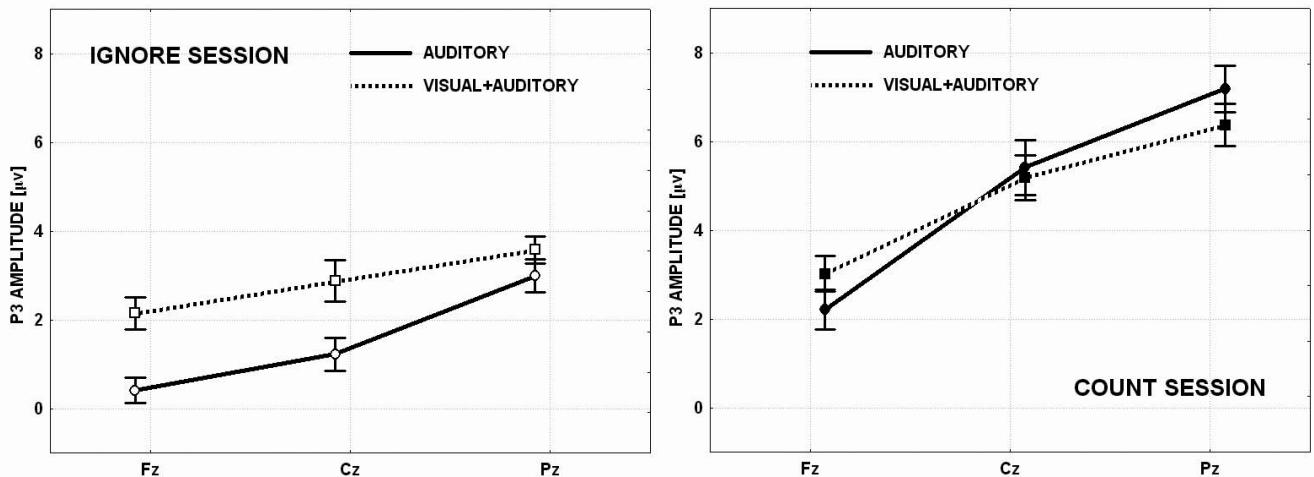


Fig. 2. Mean amplitudes of auditory P3 (\pm SEM) as a function of electrode location obtained in ignore (left panel) and count (right panel) sessions. Solid line represents auditory condition and dashed line represent visual + auditory condition.

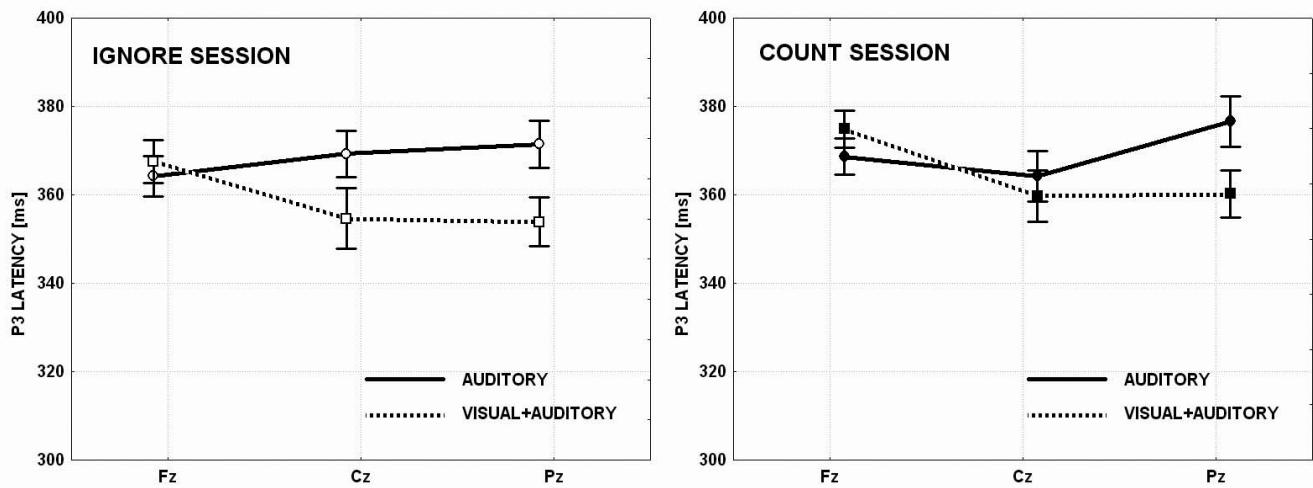


Fig. 3. Mean latencies of auditory P3 (\pm SEM) as a function of electrode location obtained in ignore (left panel) and count (right panel) sessions. Solid line represents auditory condition and dashed line represent visual + auditory condition.

interaction of SESSION \times LOCATION factors ($F_{2,62}=32.16, P<0.0001, \varepsilon=0.984$). Similarly, significant interactions between these factors were also observed when examination was limited to auditory or visual-auditory conditions ($F_{2,62}=28.46, P<0.0001, \varepsilon=0.912$, and $F_{2,62}=10.13, P<0.001, \varepsilon=0.796$, respectively).

On the other hand, a significantly more abrupt increase of P3 amplitude along the sagittal plane was observed for the auditory condition in comparison to an equivalent change obtained for the visual + auditory condition (interaction CONDITION \times LOCATION: $F_{2,62}=9.09, P<0.001, \varepsilon=0.845$). Also a significant main effect of CONDITION was found in a analysis performed across sessions ($F_{1,31}=5.19, P=0.030$). This suggests that the auditory P3 amplitude was effectively modulated not only by experimental instruction to count the tones but also by additional visual stimulation. However, when an analysis of the effect of CONDITION was separately done for each session, a significant result was found but only for the ignore ($F_{1,31}=18.84, P<0.001$), but not for the count session ($F_{1,31}=0.04, P>0.05$). At the same time significant CONDITION \times LOCATION interactions were demonstrated in a separate analysis for both ignore and count sessions ($F_{2,62}=3.73, P=0.039, \varepsilon=0.810$, and $F_{2,62}=8.95, P<0.001, \varepsilon=0.863$, respectively). These results suggest that additional visual stimulation differently modulate the amplitude of the P3 component obtained in passive and active sessions. This suggestion was partially confirmed by significant interaction CONDITION \times SESSION when the analysis was performed across all location sites ($F_{1,31}=8.55, P=0.006$). However, an examina-

tion of the effect of interaction CONDITION \times SESSION \times LOCATION delivered no significant result ($F_{2,62}=1.43, P>0.05, \varepsilon=0.775$).

When the differences between two experimental sessions and two different conditions were analyzed for the frontal location, significant main effects of SESSION ($F_{1,31}=21.25, P<0.0001$) as well as of CONDITION ($F_{1,31}=20.80, P<0.0001$) were found. The P3 amplitude obtained in the ignore session was lower than the amplitude of this component measured in the count session. Simultaneously, a larger P3 was observed in response to tones accompanied with visual stimulation in comparison to pure tones. Inspection of CONDITION \times SESSION interaction delivered almost a significant result ($F_{1,31}=3.52, P=0.070$). These results suggest that the change in task demands as well as the additional stimulation in different modality were capable of boosting the frontal response. When a similar analysis was performed for parietal P3, a much larger P3 response to tones was observed for the count session in comparison to the ignore session. This was confirmed by a highly significant main effect of SESSION ($F_{1,31}=91.02, P<0.0001$). At the same time, the amplitude of the P3 component measured in auditory and auditory + visual conditions were not significantly different (main effect of CONDITION: $F_{1,31}=0.13, P>0.05$). Inspection of CONDITION \times SESSION interaction delivered a significant result ($F_{1,31}=7.74, P=0.009$). While P3 in response to pure tones was lower than P3 in response to tones concurrently presented with pictures in the case of the ignore session ($F_{1,31}=2.92, P=0.097$), an opposite difference was

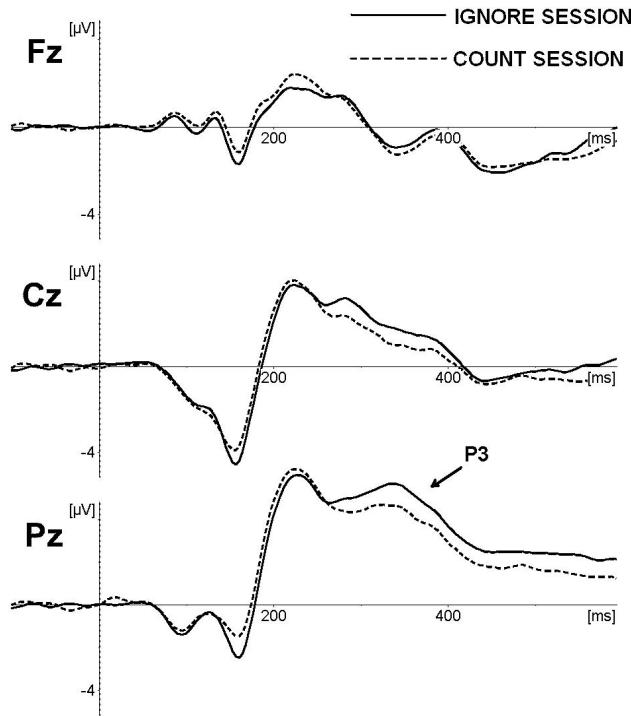


Fig. 4. Grand average ERP in response to visual stimuli recorded in ignore (solid line) and count (dashed line) sessions

observed in the count session where P3 in the auditory + visual condition was diminished in comparison to the P3 in the auditory condition ($F_{1,31}=2.99$, $P=0.094$).

Latencies of auditory P3

Latencies of the P3 deflection observed in the auditory condition increased from frontal to parietal locations, however, this effect did not reach the level of significance ($F_{2,62}=2.80$, $P=0.069$, $\varepsilon=0.941$), while a similar pattern was obtained for both the ignore and count sessions (effect of SESSION $F_{1,31}=0.09$, $P>0.05$; interaction SESSION \times LOCATION $F_{2,62}=1.54$, $P>0.05$, $\varepsilon=0.932$) as indicated in Fig. 3. In contrast to this, latencies of P3 recorded in response to tones accompanied with visual stimuli show the opposite pattern. The shortest latencies were measured on the parietal sites and the longest on the frontal sites ($F_{2,62}=7.85$, $P<0.001$, $\varepsilon=0.996$), and again, a similar pattern was obtained for both the ignore and count sessions (effect of SESSION $F_{1,31}=1.49$, $P>0.05$; interaction SESSION \times LOCATION $F_{2,62}=0.04$, $P>0.05$, $\varepsilon=0.877$). This leads to a significant interaction CONDITION \times LOCATION, when the analysis is performed across sessions ($F_{2,62}=7.85$, $P<0.001$, $\varepsilon=0.995$).

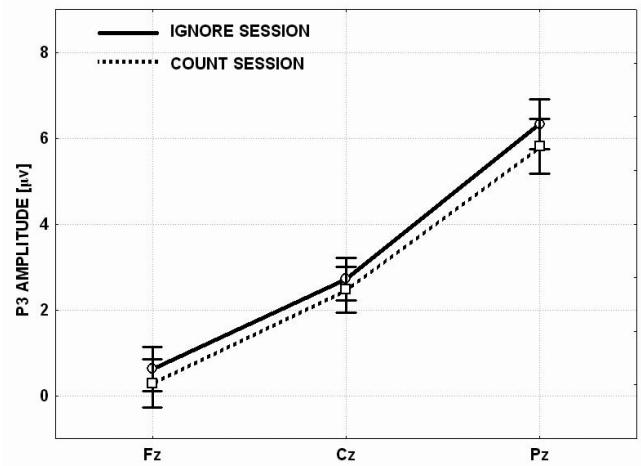


Fig. 5. Mean latencies of visual P3 (\pm SEM) as a function of electrode location obtained in ignore (solid line) and count (dashed line) sessions

Moreover, a significant main effect of CONDITION was also obtained ($F_{1,31}=4.33$, $P<0.05$). A similar significant CONDITION \times LOCATION interaction was also found when analyses were performed separately for the ignore and count session ($F_{2,62}=4.74$, $P=0.018$, $\varepsilon=0.830$, and $F_{2,62}=4.49$, $P=0.025$, $\varepsilon=0.753$, respectively). However, the main effect of CONDITION was not significant in a separate analysis for the ignore and count sessions ($F_{1,31}=2.90$, $P>0.05$, and $F_{1,31}=1.25$, $P>0.05$, respectively).

Amplitudes of visual P3

Figure 4 shows the grand average ERP elicited by pictures presented as the visual background in both the ignore and count sessions. The P3 component was clearly visible mainly at parietal sites while in other cases this was less evident. The analysis showed that P3 has a typical maximum over parietal locations (main effect of LOCATION $F_{2,62}=43.92$, $P<0.0001$, $\varepsilon=0.591$), which is indicated in Fig. 5. The same pattern was also evident when the analysis was separately done for the ignore session ($F_{2,62}=50.59$, $P<0.0001$, $\varepsilon=0.618$), as well as for the count session ($F_{2,62}=30.98$, $P<0.0001$, $\varepsilon=0.598$). This suggests that the amplitudes of the visual P3 component obtained in both sessions increased from frontal to parietal locations. No significant difference between sessions was found (main effect of SESSION $F_{1,31}=1.18$, $P>0.05$). An analysis of SESSION \times LOCATION interaction also brought no

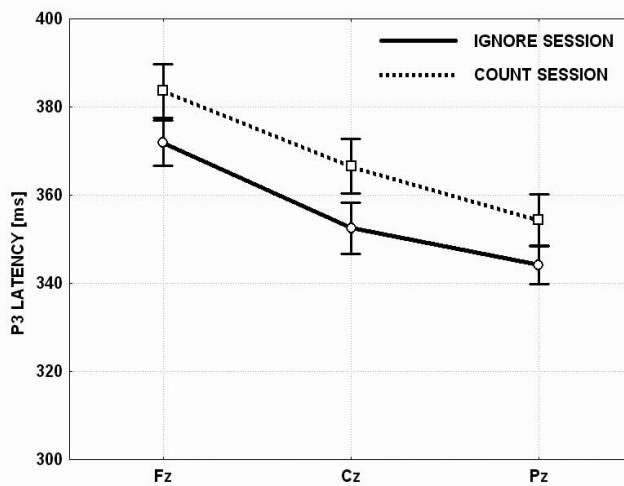


Fig. 6. Mean latencies of visual P3 (\pm SEM) as a function of electrode location obtained in ignore (solid line) and count (dashed line) sessions

significant result ($F_{2,62}=0.20$, $P>0.05$, $\varepsilon=0.618$). These results suggest that visual stimulation evoked similar brain responses in both sessions of the experiment.

Latencies of visual P3

Latencies of the visual P3 deflection observed across sessions increase from parietal to frontal locations (main effect of LOCATION: $F_{2,62}=19.86$, $P<0.0001$, $\varepsilon=0.982$), and a similar pattern was obtained for both ignore and count sessions ($F_{2,62}=15.07$, $P<0.0001$, $\varepsilon=0.989$, and $F_{2,62}=9.80$ $P<0.0003$, $\varepsilon=0.957$, respectively), which is illustrated in Fig. 6. The latencies of the visual P3 recorded in the count session were slightly longer than the latencies of P3 obtained in the ignore session (main effect of SESSION: $F_{1,31}=5.63$, $P=0.024$). An analysis of SESSION \times LOCATION interaction brought no significant result ($F_{2,62}=0.12$, $P>0.05$, $\varepsilon=0.985$) which confirms the previous suggestion that visual stimulation evoked similar brain responses in both sessions.

DISCUSSION

The differential amplitude of the parietal P3 in the ignore and count session confirmed the successful manipulation of the task instruction. When participants were informed that subsequent stimuli were irrelevant and no response was required, the response to auditory stimuli alone consisted of a small P3-like component obtained over both the parietal and the frontal location. On the con-

trary, when voluntary attention resources were provoked by the experimental instruction, a larger auditory P3 response was produced over the parietal location, along with an increase of the P3 amplitude at the frontal site. This effect of attention engagement was evident both when tones were or were not accompanied by visual stimuli. However, the processing of auditory events was cross-modally influenced by visual stimulation. When the ignore task was employed, additional visual stimulation produced a change in the amplitude of the frontal P3 component but not of the parietal P3. A different pattern of modulation was observed when an involuntary attention shift was produced by the exposition to additional visual stimuli during the count task. In this case, the amplitude of the frontal P3 evoked in response to subsequently presented auditory stimuli was also increased, while at the same time, the parietal P3 amplitude was diminished in comparison to the P3 amplitude to tones alone observed during the count task.

The effect of additional exposition to visual stimuli differed between the passive and active condition. In the passive condition (ignore session), the cross-modal influence of additional visual stimuli exposition was restricted to a change in the magnitude of the frontal response to tones, but in the active condition (count session), a similar alteration over anterior location co-existed with an additional change in the amplitude of the parietal P3 response to tones. In this case, the direction of the observed shifts in ERP was actually opposite. Simultaneously, the latency of the P3 component was shortened by additional visual stimulation in both passive and active sessions.

The presentation of visual stimuli boosted the amplitude of the auditory P3 measured over anterior locations. An increased frontal P3 may therefore stem from frontal lobe responses to visual stimuli presented shortly before. The presentation of pictures could involuntarily engage the frontal lobe and, consequently, increase an initial attention allocation (Posner and Petersen 1990). Subsequently presented auditory stimuli could therefore evoke a stronger frontal lobe response reflected in an enhanced frontal P3, in comparison to auditory stimuli presented alone. This effect was observed irrespective of the experimental instruction in both the ignore and count session. Thus, attention to stimuli presented in one modality could change the subsequent frontal response to neutral stimuli in another modality. This is consistent with Näätänen's suggestion that P3a could be regarded as a reflection of the attentional switch produced from the mismatch

between stimulus properties and the previously passively formed neuronal trace (Näätänen 1990). The frontal P3 was also significantly enhanced as the consequence of, presumably, a greater attentional focus in the active condition. This effect was obtained when tones became relevant by the experimental instruction, which is supposed to evoke controlled processing. This finding is consistent with previously reported data (Comerchero and Polich 1999, Katayama and Polich 1998), suggesting a relationship between the strength of an attentional focus and the magnitude of the P3a response. According to the task performed by the subjects, a greater attentional focus in the active condition was expected, and, indeed, an increased frontal P3 was observed. In addition, the results provided evidence that both types of frontal responses, the involuntary shift in reaction to neutral pictures and the voluntary focus provoked by the instruction, are capable of increasing the frontal P3 amplitude. Moreover, the present data support the thesis that these two effects could be, at least partially, additive.

The results presented here provide further evidence that a controlled processing of auditory stimuli could be diminished when visual material is simultaneously presented. The effects of the experimental manipulation seen in P3, reflects the evaluation of auditory events. However, the preceding exposition to visual stimuli diminished the P3 amplitude, which is considered as a correlate of the voluntary evaluation process mentioned above. The perceptual processing of the pictures and the subsequent involuntary attention shift, requires extra attentional resources, which cannot be devoted easily to the controlled processing of auditory stimuli. Thus, the processing of the relevant tones is negatively cross-modally affected by the processing of the simultaneously presented pictures, and this effect is reflected in a diminished P3. This is consistent with previous findings of Schupp and others (1997) and Cuthbert and others (1998), who obtained a similar influence of neutral and emotionally-relevant pictures on the processing of either tones or startling stimuli. They found that the P3 response was smaller when auditory stimuli were exposed on an emotionally arousing background, as compared to a neutral background. The conclusion was that a reduction in the auditory P3 amplitude reflects a greater allocation of attentional resources to more demanding stimulation. Comparable findings were also reported by Oray and coauthors (2002), who obtained a reduced auditory P3 amplitude in response to tone bursts presented along with pictures, in comparison to tones alone. The reduction of

the auditory P3 response observed in the present study is also compatible with the findings of other researchers (Michalski 2001, Milner and Michalski 2003), who suggested that cortical responsiveness to irrelevant stimulation is reduced during the occurrence of the P3. They found that early stages of visual processing could be affected when stimuli presented shortly before are engaging attention.

CONCLUSIONS

Auditory stimuli evoke a P3 component of different magnitude over frontal and parietal locations. This is mediated both by attention demands and by parallel processing of visual stimuli. In particular, the P3 recorded over the parietal cortex is strongly dependent on the cognitive load. When attention is voluntarily allocated to relevant stimuli an evident P3 is obtained. However, parallel visual processing could decrease the strength of this effect. Thus, a parietal P3 could be affected in a cross-modal way by an involuntarily attention shift to visual stimuli and this effect represents allocation of attention resources. The frontal P3 is found to be related to involuntary (or voluntary) attention shift. Increases in P3 amplitude on frontal locations are obtained in two conditions: (1) when auditory stimuli have to be counted by the subjects (voluntary shift), and (2) when attention is directed to visual stimuli and tones are unexpectedly presented (involuntary shift). These results lead to the suggestion that the involuntary processing of visual stimuli might cross-modally change the processing of auditory stimuli. This effect could be observed not only when the perceived stimuli have a special affective meaning, but even when the stimuli are neutral. However, this deficit in allocation of attentional resources is restricted to the active condition only, when the matching of a template with incoming information results in a distinct P3 component. The possible source of the effect is a change in the activity of the frontal cortex. Frontal neurons project to more posterior parts of the brain, such as the inferior temporal cortex and parietal cortex (Yamaguchi and Knight 1991b). Single-cell recordings in animals and neuroimaging studies in humans, provide evidence that the dorsolateral prefrontal cortex is important for holding temporary representations in working memory. The presentation of visual pictures evokes activity in the anterior attention system, reflecting the involuntary processing of new templates in working memory. Another template is created as the result of the experimental instruction to count the

auditory stimuli during the active session. Both processes, which can also occur independently, cause a change in the activity of the frontal cortex, and this is expressed in an increased P3a amplitude.

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