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Multi-modal effects of local context on target detection: Evidence from P3b

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Abstract

We used the P300 component to investigate how changes in local context influenced the ability to detect target stimuli. Local context was defined as the occurrence of a short predictive series of stimuli before delivery of a target event. EEG was recorded in 12 subjects during auditory and visual sessions. Stimuli were presented in the center of the auditory and visual field and consisted of 15% targets (1000 Hz tone or downward facing triangle) and 85% of equal amounts of three types of standards (1500 Hz, 2000 Hz and 2500 Hz tones or triangles facing left, upwards and right). Recording blocks consisted of targets preceded by either randomized sequences of standards or by sequences including a three-standard predictive sequence signaling the occurrence of a subsequent target event. Subjects pressed a button in response to targets. Peak target P300 (P3b) amplitude and latency were evaluated for targets after predictive and non-predictive sequences using conventional averaging and a novel single-trial analysis procedure. Reaction times were shorter for predictable targets than for non-predicted targets. P3b latency was shorter for predicted targets than for non-predictive targets, and there were no significant P3b amplitude differences between predicted and random targets, as determined by both conventional averaging and single-trial analysis. Comparable effects on amplitude and latency were observed in both the auditory and visual modalities. The results indicate that local context has differential effects on P3b amplitude and latency, and exerts modality independent effects on cognitive processing.

Keywords

context; P3b; multi-modal; EEG; ASEO

Introduction

We rapidly and fluidly extract and utilize information from our environment to guide goal-oriented behavior and to facilitate the detection of task-relevant stimuli. The use of relevant information to guide our behavior allows one to mediate appropriate behavioral responses as a function of local context. However, the neural mechanisms underlying this mental process are not well understood.

Evidence from neuropsychological, event-related potential (ERP) and neuroimaging studies supports a key role of the lateral prefrontal cortex (LPFC) in contextual processing. Studies of patients with schizophrenia, showing an association of prefrontal dysfunction with impairment in context processing, suggests that this cortical area has a critical role in the processing of context (MacDonald et al. 2005; Barch et al., 2001). The proposition is that lateral prefrontal cortex (LPFC) recodes information into context representations (Cohen and Servan-Schreiber, 1992; MacDonald et al., 2000). That is, information such as task instructions, a cue or the processing of preceding sequential stimuli, are maintained in the LPFC to facilitate appropriate response to target stimuli (Cohen and Servan-Schreiber, 1992; MacDonald et al., 2000; Huettel et al., 2005). Neuroimaging data from Huettel and colleagues (2005) have also reported that LPFC has a critical role in the resolution of short term uncertainty.

Electrophysiological studies also support a key role of LPFC in contextual processing. For instance, contextual processing has been linked to the P300 component of the ERP (Squires et al., 1976; Donchin and Coles, 1988; Poulsen et al., 2005; Polich and Criado, 2006). One hypothesis is that P300 generation reflects a process wherein a stimulus is evaluated in the context of the previous stimuli by comparing it with working memory content (Donchin and Coles, 1988; Polich 2003; Polich and Criado, 2006). Other theories link P300 with such processes as cognitive closure, stimulus categorization (Verleger, 1988) and template matching (Squires et al., 1973; Chao et al., 1995). In the case of template matching, the closer the match of a stimulus to a template, the larger and earlier the P300 (Squires et al., 1973). ERP and neurophysiological data from neurological patients with LPFC damage also support a role of this brain region in contextual processing (Barcelo and Knight, 2007). These lesion-ERP findings in lateral frontal damage patients link the P300 family of ERPs to the guided activation model of frontal function (Miller and Cohen, 2001; Barcelo and Knight, 2007). The extant literature supports the notion that hypotheses about the environment are continuously generated as a function of incoming information (Donchin and Coles, 1988), and the P3b ERP component is associated with the evaluation of these as a function of context (Squires et al., 1976).

The target P300, known as the P3b, is elicited by the classical oddball target detection task and has a posterior-parietal scalp distribution (Squires et al., 1975; Polich, 2003). P3b latency is a measure of the timing of mental processes reflected by the component, whereas P3b amplitude has been proposed to reflect the intensity of these processes (Kok, 2001). P3b may be influenced by three main variables (Johnson, 1986): information transmission (equivocation and allocation of attention, also proposed to reflect resources invested in identification of a stimulus, Kok, 2001), subjective probability (affected by global probabilities and sequential expectancies) and stimulus meaning (a function of stimulus complexity, task complexity and stimulus value). P3b amplitude and latency are affected by information transmission (reduced information transmitted by the stimulus, results in smaller P3b amplitude and longer latency, Sutton et al., 1965, 1967; Johnson, 1986); global probability (higher global probability of a target stimulus results in smaller amplitude and shorter latency P3b, Polich and Bondurant, 1997; Johnson, 1986); sequential effects (P3b amplitude is larger and latency is shorter for targets preceded by a longer string of standards, compared to targets preceded by a short string of standards, Squires et al., 1976; Holm et al., 2006); and complexity of the stimulus (the more complex the stimulus, the larger the amplitude and the longer the latency of the P3b (Kutas et al., 1977; Johnson, 1986). P3b amplitude increases with increasing task complexity, and increasing stimulus value or relevance to the task (Wilkinson and Morlock, 1967; Johnson, 1986). P3b amplitude is also affected by expectancy such that the less expected a stimulus is in the context of a sequential series of stimuli (i.e., if a repetitive pattern of stimuli is discontinued), the bigger the P3b amplitude (Squires et al., 1976; Johnson and Donchin, 1980; Polich and Bondurant, 1997). In addition, P3b amplitude has been shown to be suppressed in patients with prefrontal lesions (Barcelo et al., 2000, 2007; Alain et al., 1998;

Frodl-Bauch et al., 1999), supporting an important role of the prefrontal cortex in the modulation of the P3b component.

The aim of the present study was to use P3b ERP to examine the effects of a predictive sequence on local contextual processing. Experimentally, we modified the classical oddball target task such that instead of only one standard occurring there were equal amounts of three different standards as well as one designated target. This design allowed us to introduce a sequence that predicted subsequent targets, and to compare these to targets occurring randomly. We investigated the effects of local context by comparing predicted, random targets and the predictive sequence, to determine whether P3b amplitude increases as a function of the build-up of contextual information. Furthermore, we explored these effects in both the auditory and visual modalities to determine whether local context effects depended on the sensory modality. Methodologically, we extended the traditional ERP analysis method by incorporating single-trial analysis. Specifically, we used a novel technique called ASEO (Analysis of Single-trial Event-related potentials and Ongoing activity) to estimate P3b amplitude and latency of predicted and random targets on a single trial basis to determine how these two parameters are affected by predictive local context.

Method

Subjects

Fourteen subjects (mean age = 25 years, 6 females) participated in the study. All the subjects were right-handed, had normal vision and audition and had no history of psychiatric or neurological problems. Subjects were consented prior to being tested and were paid for their participation. The Committee for the Protection of Human Subjects for University California, Berkeley approved the study. Reliable recordings were obtained from 12 subjects in both the visual and auditory modality, (in 2 of these subjects the auditory sessions were excluded from further analysis, see below for details) and from another 2 subjects in the auditory modality only, such that overall 12 recordings were obtained for each modality.

Task

Subjects sat in a sound attenuated booth 110 cm in-front of a 21-inch PC-computer screen. Stimuli were presented in the visual and auditory modalities in two separate sessions. Stimuli consisted of 15% targets (1000 Hz tone or downward facing triangle) and 85% of equal amounts of three types of standards (1500 Hz, 2000 Hz and 2500 Hz tones at 65 dB SPL, with 9ms rise time or triangles facing left, upwards and right). In each block a total of 127 stimuli (19 targets, 36 of each standard type) were presented each for 100 ms and ISI of 1 sec. Recording blocks consisted of targets preceded by either randomized sequences of standards or by sequences including a three-standard predictive sequence. Figure 1 illustrates an example of randomized and predicted sequences. Each block consisted of 10 different randomized sequences of standards (1-10 standards long) preceding the target; and 8 sequences of standards (3-10 standards long) with a predictive sequence preceding the target in each. Visual stimuli were presented centrally on a computer screen and auditory stimuli from a central loudspeaker, both 110 cm in front of the subject. The subject was asked to centrally fixate throughout the recordings in both modality sessions. Each session in one of the modalities consisted of 12 different blocks, displayed in randomized order, each approximately 2.3 minutes long. Auditory and visual sessions were counterbalanced across subjects, such that the same number of subjects performed the auditory session followed by the visual session and vice versa.

Subjects performed a brief training session to ensure they were able to detect the target accurately. Subjects were then introduced to the predictive sequence before the recordings began and were aware that it would be a 100% predictive of a target, but that targets would

also appear randomly throughout the block. Subjects were asked to press a button each time a target was presented and to pay attention and look for the predictive sequence. Upon post-screening subjects who reported that they did not notice the sequence were excluded from analysis (two auditory sessions in two of the subjects). Stimulus presentation and response recordings were controlled using E-prime (Psychology Software Tools, Inc., Pittsburgh, USA).

Recording

EEG was recorded from 64 electrode array using the ActiveTwo system (Biosemi, The Netherlands). External electrodes above and below the right eye monitored vertical eye movements and electrodes placed laterally to the left and right eyes monitored horizontal eye movements. Linked ears were used as reference. Signals were amplified and digitized at 512 Hz and filtered at 0.16-100 Hz. Post processing and ERP analysis of the data was performed using Brain Vision Analyzer (Brain Products GmbH, Germany). All channels were re-referenced to averaged earlobes.

ERP Analysis

Prior to ERP analysis ocular movements were defined using ICA and were removed by a linear derivation using Brain Vision Analyzer. Epochs containing misses (no button press 100-1100 ms post stimulus onset) were excluded from further analysis. EEG signals were filtered at 0.5-30 Hz for subsequent analysis. EEG signals were sorted and averaged relative to the stimulus onset, with epochs set from -100 to 1000 ms relative to stimulus onset. EEG epochs with amplitude of more than 75 μV at any electrode were excluded.

P3b was determined as the most positive point in the latency range of 200-700 ms in the auditory modality and 250-700 ms in the visual modality. N1 was determined as the most negative peak in the latency range of 50-200 ms.

Peak P3b amplitude (measured in μV) and latencies (measured in milliseconds) at Pz were evaluated for 6 conditions: targets after predictive sequences (predicted), targets after non predictive random sequences (random), random preceding standards (standards) and the three standards comprising the predicting sequence (n-3, n-2 and n-1, n-1 being the last most-informative stimulus). To have comparable ERPs in the predicted vs. the random targets, only the random targets that were preceded by 3-10 random standards were included in the analysis. There were comparable number of trials for predicted (61 ± 5 , auditory and 62 ± 8 , visual) and random target (61 ± 6 , auditory and 66 ± 8 , visual) conditions after removal of misses and artifacts. We also evaluated P3 amplitude at Pz for each of the three standards presented randomly, that is, not as a part of the predictive sequence (Sn-1, Sn-2 and Sn-3) in order to compare each of these standards to its counterpart when presented within the predictive sequence.

For scalp distribution comparisons of P3b in the two target conditions, peak P3b amplitudes were measured in each condition across electrodes Fz, Cz, and Pz.

To demonstrate the early positive shift that was observed in the predicted target compared to the random target condition, a difference wave subtracting random targets from predicted targets was evaluated at Fz, Cz and Pz. Peak amplitude and latency were evaluated for this difference wave (DW), by determining the most positive point in the latency range of 150-350 ms in both modalities.

To compare the early perceptual processes between the two target conditions, peak N1 amplitudes (measured in μV) were determined at Fz for the auditory modality and at PO7 and PO8 in the visual modality for both predicted and random targets. We also assessed the contingent negative variation (CNV) to examine whether local context influenced preparatory

attention during the detection of the predictive sequence (Walter et al., 1964). CNV epochs were set from -200 to 1100 ms relative to stimulus onset. CNV was evaluated as the mean amplitude (measured in μV) for the range of 900 -1100 ms post stimulus onset at midline electrodes (Fz, FCz, Cz and CPz). CNV was evaluated for the three standards consisting of the predictive sequence (n-1, n-2 and n-3) and also for the random standard preceding the predictive sequence (n-4).

Analysis of variance (ANOVA) was performed with the Greenhouse-Geisser correction, followed by post-hoc parametric paired t-tests, Sidak corrected for multiple comparisons unless otherwise stated. Mean values with SEM are used throughout the text.

Single-trial Analysis

ERPs components such as the P3b are known to vary from trial to trial in both amplitude and latency (Kutas et al., 1977; Truccolo et al., 2002; Holm et al., 2006). Thus, single-trial amplitude and latency may contribute additional information not contained in the ERP. We augmented the ERP analysis by further subjecting the P3b data to the analysis of a technique called ASEO, which stands for Analysis of Single-trial Event-related potentials and Ongoing activity (Xu et al., 2007). In this method the single-trial EEG is modeled as the linear combination of multiple event-related components that are relatively phase-locked to the onset of stimulus and ongoing activity (Truccolo et al., 2002; Chen et al., 2006). In this Variable Signal Plus Ongoing Activity (VSPOA) model, the ongoing activity is considered an autoregressive (AR) random process. ASEO estimates the single-trial parameters such as amplitudes and latencies of the ERP components and the ongoing activity in two steps. In the frequency step, based on the most recently available estimate of the power spectrum of the ongoing activity, the waveforms of the ERP components and their single-trial parameters are estimated in the frequency domain by the maximum likelihood method. In the time step, the AR model parameters of the ongoing activity are estimated in the time domain based on the most recently estimated ERP parameters using an approximate maximum likelihood method. These two steps are iterated until no further improvement is seen in the estimated quantities.

EEG signals were filtered (0.5 - 50 Hz) and downsampled to 256 Hz. One component between 180 ms (auditory) or 200 ms (visual) and 800 ms post-stimulus presentation was investigated at Pz for targets following both predictive and non-predictive random sequences. Distributions were obtained for both peak P3b amplitude and latency. A Kolmogorov Smirnov test showed these variables to be non-normally distributed. Thus, the post-hoc Mann-Whitney U test was used to compare the distributions between predictable and random non-predictable conditions. Spearman's correlations were computed between peak P3b amplitude and latency across trials in each condition (predicted and random targets) for each subject (total of 24 correlations in each modality).

Results

Behavioral results

Mean accuracy was $94 \pm 2\%$ and $97 \pm 1\%$ for the auditory and visual tasks, respectively. Paired t-tests showed that the reaction times (RT) for the predicted targets (mean RT = 325 ± 32 ms and 320 ± 25 ms for auditory and visual, respectively) were shorter than those for random targets (mean RT = 452 ± 12 ms and 476 ± 16 ms for auditory and visual, respectively) in both the auditory and visual modalities ($t[11] = 4.60$, $p=0.001$ and $t[11] = 6.33$, $p<0.0001$ for auditory and visual, respectively). RT values are illustrated in figure 2.

P3b

Grand-averaged ERPs across the 12 subjects at Pz elicited by random, predicted targets, standards and the three standards comprising the predicting sequence (n-3, n-2 and n-1, n-1 being the last most-informative stimulus) are shown for the auditory modality in figure 3A and for the visual modality in figure 3B. Both modalities show a robust posterior P3 component for targets with a shift in latency between predicted and random targets.

We performed four separate ANOVAs for each modality (auditory and visual) and for each peak P3b variable (amplitude and latency), with condition (random, predicted targets, standards and the three standards comprising the predicting sequence: n-3, n-2, and n-1) as a factor.

There was a main effect for condition in the comparison of peak P3b latency in both the auditory ($F[5,55]=5.04$, $p=0.003$) and visual ($F[5,55]=8.68$, $p<0.0001$) modalities. Post-hoc t-tests showed that peak P3b latency was shorter for predicted targets (mean = 288 ± 14 ms and 347 ± 11 ms for auditory and visual, respectively) compared to the peak P3b latency for random targets (mean = 375 ± 15 ms and 455 ± 20 ms for auditory and visual, respectively; $t[11] = 4.35$, $p=0.001$ for auditory and $t[11] = 4.70$, $p=0.001$ for visual). These comparisons are displayed in figure 4.

There was a main effect for condition in the comparison of peak P3b amplitude across the six conditions in the auditory ($F[5,55]=28.76$, $p<0.0001$) and visual ($F[5,55]=14.39$, $p<0.0001$) modalities. In the auditory modality, post-hoc tests, corrected for multiple comparisons, showed that peak P3b amplitude was larger in predicted targets (13.19 ± 1.08 μV), random targets (13.63 ± 1.57 μV) and n-1 (10.32 ± 1.40 μV) compared to standards (4.14 ± 0.78 μV , $p<0.01$), n-3 (6.09 ± 0.70 μV , $p<0.05$) and n-2 (5.70 ± 0.95 μV , $p<0.01$). However, there was no significant difference in P3b amplitude between random and predicted targets. Further analysis of each of the predictive standards n-1, n-2 and n-3 compared to each of these standards presented randomly (Sn-1, Sn-2, Sn-3) showed P3b amplitudes in n-1 (10.32 ± 1.40 μV) to be larger compared to Sn-1 (3.66 ± 0.67 μV , $t[11] = 6.93$, $p<0.0001$), n-2 (5.70 ± 0.95 μV) was larger compared to Sn-2 (3.70 ± 0.99 μV , $t[11] = 2.77$, $p=0.02$), and n-3 (6.09 ± 0.70 μV) was larger compared to Sn-3 (4.02 ± 0.67 μV , $t[11] = 3.35$, $p=0.006$). In the visual modality, post-hoc tests corrected for multiple comparisons, showed peak P3b amplitude to be larger in predicted (20.55 ± 1.96 μV) and random (20.37 ± 1.91 μV) targets compared to standards (9.13 ± 0.88 μV , $p=0.001$) and compared to n-3 (11.44 ± 1.35 μV , $p=0.002$). However, there was no significant difference in P3b amplitude between random and predicted targets. Further analysis of each of the predictive standards n-1, n-2 and n-3 compared to each of these standards presented randomly (Sn-1, Sn-2, Sn-3) showed P3b amplitudes in n-1 (14.31 ± 1.85 μV) to be larger compared to Sn-1 (9.04 ± 0.92 μV , $t[11] = 3.22$, $p=0.008$), there was a trend for n-2 (12.98 ± 2.10 μV) to be larger than Sn-2 (9.02 ± 0.87 μV , $t[11] = 2.16$, $p=0.05$), and n-3 (11.44 ± 1.35 μV) was larger compared to Sn-3 (9.39 ± 0.86 μV , $t[11] = 2.73$, $p=0.02$). Figure 5 demonstrates the gradual increase in amplitude with increasing task-relevance of the stimuli in both the auditory (5A) and visual (5B) modalities.

To compare scalp distributions of the target conditions we performed an ANOVA with electrode (Fz, Cz and Pz) and condition (predicted and random targets) as factors in each modality. There was a main effect for electrode in the auditory ($F[2,22] = 45.71$, $p<0.0001$) and visual ($F[2,22] = 20.04$, $p<0.0001$) modalities. There was no significant main effect for condition in both modalities. Post-hoc assessment showed P3b amplitude at Pz to be larger than those at Cz for random targets (10.51 ± 1.93 μV , $t[11] = 4.07$, $p=0.002$) and to be larger than Fz for both predicted (8.80 ± 1.61 μV , $t[11] = 4.75$, $p=0.001$) and random (7.58 ± 1.72 μV , $t[11] = 6.96$, $p<0.0001$) targets, in the auditory modality. P3b amplitudes were larger at Pz than at Fz for both predicted (15.72 ± 1.76 μV , $t[11] = 4.95$, $p<0.0001$) and random (15.11

$\pm 1.87 \mu\text{V}$, $t[11] = 3.63$, $p=0.004$) targets in the visual modality. Scalp distributions of predicted and random targets are illustrated in figure 6.

One sample t-test showed a significant difference wave at Pz (mean amplitude = $9.02 \pm 1.17 \mu\text{V}$, for auditory and $12.14 \pm 1.87 \mu\text{V}$, for visual) in both modalities ($t[11] = 7.66$, $p<0.0001$ for auditory, $t[11] = 6.50$, $p<0.0001$ for visual), demonstrating the early (mean latency = 236 ± 8 ms and 280 ± 7 ms, for auditory and visual, respectively) positive shift observed in the predicted target compared to the random target condition. To compare the scalp distribution of the difference wave (DW), an ANOVA with electrode (Fz, Cz and Pz) as a factor was performed. There was a main effect for electrode in the auditory ($F[2,22] = 4.36$, $p=0.04$) and visual ($F[2,22] = 25.38$, $p<0.0001$) modalities. Post-hoc assessment showed DW amplitude at Pz and Cz ($8.52 \pm 1.18 \mu\text{V}$) to be larger than those at Fz ($6.96 \pm 0.79 \mu\text{V}$, $t[11] = 2.22$, $p=0.048$ and $t[11] = 2.83$, $p=0.016$, respectively) in the auditory modality. DW amplitudes were larger at Pz than at Cz ($10.80 \pm 1.98 \mu\text{V}$, $t[11] = 2.29$, $p=0.04$) and Fz ($7.73 \pm 1.72 \mu\text{V}$, $t[11] = 6.62$, $p<0.0001$) and amplitude at Cz was larger than Fz ($t[11] = 4.74$, $p=0.001$) in the visual modality. Thus, this difference wave has a posterior – parietal scalp distribution similar to that of P3b in both modalities as is illustrated in figure 6.

Pearson's correlations between auditory and visual P3b amplitudes across the 10 subjects that had recordings from both modalities, showed that these co-varied for both predicted ($r=0.742$, $p=0.01$) and random ($r=0.645$, $p=0.04$) targets.

N1

A paired t-test comparing the peak N1 amplitude at Fz between predicted and random targets, in the auditory modality showed no significant differences. We utilized an ANOVA with electrode (P07 and P08) and condition (predicted and random targets) as factors to compare the peak N1 amplitude between predicted and random targets in the visual modality. There was no significant main effect for condition or electrode. N1 ERPs are illustrated in figure 7.

CNV

For the comparison of the mean CNV amplitude we collapsed the data from the standards consisting of the predictive sequence n-1 and n-2 and called this condition “informative”, and the data from the standard n-3 of the predictive sequence and the random standard before the sequence (n-4) and called this condition “non-informative”. We performed two separate ANOVAs for the auditory and visual modality, with electrode (Fz, FCz, Cz and CPz) and condition (informative, not informative) as factors. In the auditory modality there was a significant main effect for condition ($F[1,11] = 10.43$, $p=0.008$), but no significant main effect for electrode. Post-hoc t-tests showed larger mean CNV amplitude in the informative compared to the non informative condition at CPz ($t[11] = 3.81$, $p=0.003$), Cz ($t[11] = 2.83$, $p=0.02$), FCz ($t[11] = 2.72$, $p=0.02$) and Fz ($t[11] = 2.53$, $p=0.03$). In the visual modality there was no significant main effect for condition or electrode, although a similar effect was observed to that in the auditory modality. CNV results are illustrated in figure 8.

ASEO single-trial analysis of target P3b

Since P3b amplitude showed no significant difference between the two target conditions, we applied a novel single-trial method (ASEO) to further explore the reliability of this null effect for P3b amplitude. ASEO estimated single-trial amplitude and latency for a typical subject are shown in figure 9A (auditory) and 9B (visual). While no difference is seen in the amplitude distributions, P3b latency is clearly shorter for the predicted than for the random condition. This is consistent with the ERP findings reported earlier. The results for all 12 subjects are illustrated in figure 9C for the auditory modality and in ^{9D} for the visual modality, where each subject's P3b amplitude and latency were normalized using a Z-transformation so that the

population results could be displayed. Significant decreases were found for single-trial P3b latencies ($p < 0.05$) in the predictable compared with the random non-predictable condition in 10/12 subjects ($p = 0.003$ Fisher's exact test) for the auditory modality, and in 11/12 subjects ($p = 0.001$, Fisher's exact test) for the visual modality. Single-trial P3b amplitudes, however, showed no significant differences for the predictable compared with the random non-predictable condition in 8/12 subjects in both modalities.

The relation between single-trial P3b amplitude and latency was addressed by a correlation analysis. We found no significant correlations between the two variables in 42/48 cases (20/24 for auditory, 22/24 for visual). The mean correlations between P3b amplitude and P3b latency in the auditory modality were -0.11 ± 0.1 for predicted targets and 0.10 ± 0.07 for random targets. The mean correlations between P3b amplitude and P3b latency in the visual modality were -0.06 ± 0.07 for predicted targets and 0.10 ± 0.09 for random targets. The independence of the two variables is also evident in the scatter plots in figure 9A-D. ASEO reliably discriminated between predictable and random non-predictable conditions (figure 9) in both modalities, showing reduced P3b latencies of the predictable targets.

Discussion

This study demonstrated that predictive local context affects target detection by reducing the duration of stimulus evaluation. This effect was associated with both faster reaction times and shortened P3b latencies. P3b amplitude increased with task-informative stimuli, reaching its maximum in the two target conditions. However, there were no significant differences in P3b amplitude between predicted and random targets, suggesting that in this easy discrimination task, local prediction only affected speed of processing. Importantly these local context effects were independent of the sensory modality of the stimulus. A novel single-trial analysis provided further support for these findings. The P3b latency estimated on a trial by trial basis reliably discriminated between predictable and random non-predictable conditions and no significant correlations between P3b amplitude and latency were observed for either the predicted or the random targets, suggesting that these two variables were independently modulated.

P3b latency and duration of stimulus evaluation

P3b latency was shorter for sequence predicted targets than for targets after non-predictive sequences. These results were confirmed by ASEO single-trial analysis, which discriminated reliably between predicted and random targets. In addition, we found that the P3 latency shift was related to an early positive shift, with a similar posterior-parietal scalp distribution as that observed for the P3b. This earlier positive shift was only seen in the predicted target as compared to the random target condition. This early positivity may reflect an early template match and suggests that P3b reflects processes of detection or preparatory attention of working memory rather than decision closure. The finding that P3b latency is shortened by task-informative preceding stimuli is supported by evidence from earlier studies (Duncan-Johnson, 1981; Duncan-Johnson and Donchin, 1982) showing that P3b latency is shorter for highly probable targets (80% predictable) than for less probable targets (20% predictable). P3b latency has been shown to be sensitive to the duration of the stimulus evaluation process (Kutas et al., 1977; Duncan-Johnson, 1981; McCarthy and Donchin, 1981; Hillyard and Kutas, 1983; Ford et al., 1982). Furthermore, our findings suggest that this facilitation in stimulus evaluation is cognitive rather than perceptual, since targets were identical in their physical features and there were no significant N1 amplitude differences between predicted and random targets (Hillyard and Kutas, 1983). Latency differences in our study were associated with parallel behavioral results showing shorter reaction times for predicted targets. This is in line with studies showing reaction times to be correlated with P3b latencies in easy discrimination tasks requiring accuracy (Kutas et al., 1977; Verleger, 1997), such as the task utilized here.

P3b amplitude and task relevance

The major findings regarding the effects of local context on P3b amplitude were twofold. First, we found that the P3b amplitude increased gradually with task-relevance, with a significant P3b induced by the last most-informative standard of the predicting sequence, and largest P3b for targets. This is supported by Sawaki and Katayama (2006) who have also shown that P3b amplitude increases as a function of task-relevance. Since the predicting sequence induced a significant P3b compared to the same standards presented in a randomized non-predictive sequence, it seems that it became a secondary target for the subjects. The increase in P3b amplitude in the predictive sequence supports an accumulation of information from the preceding trials. This is also supported by a significant increase in CNV in the auditory modality between stimuli with predictive context compared to those without predictive information. The increase in CNV indicates increased preparatory attention (Walter et al., 1964) to the more informative stimuli of the sequence.

Second, we demonstrated comparable P3b amplitudes for random and predicted targets with both conventional averaging and single-trial analysis. This is supported by Barcelo and Knight (2007), who showed no effect of contextual predictability on P3b amplitudes and by a study by Munson et al. (1984) that showed no significant differences in P3b amplitude between correctly predicted and incorrectly predicted stimuli. However, our finding does contradict evidence showing that P3b amplitude decreases with the degree of expectancy (Sutton et al., 1967; Squires et al., 1976; Donchin and Coles, 1988; Johnson, 1986) or prediction (Duncan-Johnson and Donchin, 1982; Suwazono et al., 2000). Numerous studies have demonstrated the effect of decision confidence on P3b amplitude (Hillyard et al., 1971; Squires et al., 1973, 1975; Parasurman et al., 1982; Hillyard et al., 1971; Squires et al., 1973). These studies document that the greater the decision confidence, the larger and earlier the P3b. We used a simple discrimination task, and it may be the case that the decision confidence was similar in the detection of a random target to that of a predicted target, and thus no significant amplitude differences were observed. However, we cannot rule out the possibility that a greater decision confidence in the detection of the predicted targets lead to earlier P3s. The fact that these results differ from those of earlier studies examining prediction effects (Duncan-Johnson and Donchin, 1982; Suwazono et al., 2000), may be due to differences in the design of the tasks. Duncan-Johnson and Donchin (1982) manipulated the probability (0.20, 0.80, 0.50) of pairs of stimuli, where the second stimulus had to be predicted given the first stimulus. This task has a higher degree of difficulty than the prediction task used in the current study, and therefore decision confidence may have been significantly affected. Suwazono and colleagues (2000) who examined the effects of the predictive value of novels on target detection, found P3b amplitude to be larger for non-predictive (40% and 20%) compared to 100% predictive targets. It is difficult to compare these results with our study since shorter ISIs (200-900ms) were used and the task was more difficult. In addition, novel stimuli employed in the Swazano et al. (2000) study, introduced either alerting or distracting elements according to the predictive information they contained and thus any amplitude changes observed may have arisen from the interaction between novelty and predictive effects.

In contrast our study used the standards themselves, rather than introducing novel stimuli, in order to provide predictive information about the targets. Our use of three standards is an important difference in comparison to most of the studies performed to date, which have employed only one standard. The implication of this change is that sequential expectancies that are generated when a series of repeated standards are displayed may not apply here. Therefore, the large P3b that is generated when a sequence of standards is discontinued, as compared to an expected repeated continuation of standards (Squires et al., 1976; Donchin and Coles, 1988) may not be an appropriate comparison with our study of predicted expectations.

We propose that effects of expectancy of pattern continuation were abolished in our task and what determined the magnitude of the P3b amplitude was the task-relevance of the stimulus. Hence, no P3b amplitude differences were observed between the predicted and random targets, since those were both equally relevant for the performance of the task. The advantage of the current paradigm was that it minimized the variables effecting P3b as much as possible, such that discrimination difficulty was minimal, decision confidence of target detection was high, and predictive targets could be predicted with 100% certainty. In that light it seems that in our study predictive context only manipulated the duration of stimulus evaluation of predicted targets compared to random targets. Task-relevance was manipulated with the build-up of contextual information (during the detection of the predictive sequence) and reached its maximum in both the predicted and random targets.

Modality independent effects of local context

Comparable effects of the predictive sequence on P3b amplitude and latency were demonstrated for both the auditory and visual sessions suggesting a top-down modality independent mechanism. This is in line with the hypothesis associating predictive context to prefrontal top-down control networks (Cohen and Servan-Schreiber, 1992; MacDonald et al., 2000; Barch et al., 2001; Miller and Cohen, 2001; MacDonald et al., 2005; Huettel et al., 2005; Barcelo and Knight, 2007). These studies provide evidence showing that LPFC, has a key role in the maintenance and representation of contextual information. Furthermore, the LPFC is also involved in top-down control of goal-oriented, context appropriate responses and behavior (Cohen and Servan-Schreiber, 1992; MacDonald et al., 2000, 2005; Barcelo and Knight, 2007). This top-down control, also referred to as the “internal representation of context” (Cohen and Servan-Schreiber, 1992), involves updating and maintenance of task-relevant information in a form that can be used to select or execute appropriate responses. Contextual information may include a set of task instructions, specific prior stimuli, or the processing of a sequence of prior stimuli (Cohen and Servan-Schreiber, 1992; Barch et al., 2001). This is the type of information that subjects had to utilize in the present study, and therefore, it is reasonable to assume that the prefrontal cortex was engaged in the detection and prediction of targets during the task. Imaging studies have shown prefrontal activation, including the middle frontal gyrus, during target detection in a standard oddball task (McCarthy et al., 1997; Kiehl et al., 2001; Low et al., 2006). We propose that there is an additional contextual activation of the prefrontal cortex during the detection of predictive targets.

Independent modulation of P3b variables

Single-trial analysis allowed for correlations between latency and amplitude of the P3b component and showed that these two variables were not significantly correlated and thus, may be modulated independently of each other. This is supported by pharmacological studies by Fowler et al. (1988; 1997), demonstrating differential effects of nitric oxide or barbiturate on P300 latency and amplitude, where only the P300 latency was affected (increased) by the drugs, and not P300 amplitude. In both of these studies either no correlations (Fowler et al., 1988) or a low average positive correlation of 0.22 (Fowler et al. 1997) were found between P300 latency and P300 amplitude on a single trial basis, which is consistent with our results. The authors proposed the existence of independent mechanisms for the two variables affecting the P300 component, which is further supported by the findings of the present investigation, where local context had differential effects on P3b amplitude and latency.

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References

- Alain C, Hargrave R, Woods DL. Processing of auditory stimuli during visual attention in patients with schizophrenia. *Biological Psychiatry* 1988;44:1151–1159. [PubMed: 9836018]
- Barcelo F, Knight RT. An information-theoretical approach to contextual processing in the human brain: evidence from prefrontal lesions. *Cerebral Cortex*, 2007 2007;17:i51–60.
- Barcelo F, Suwazano S, Knight RT. Prefrontal modulation of visual processing in humans. *Nature Neuroscience* 2000;3:399–403.
- Barch DM, Carter CS, Braver TS, Sabb FW, MacDonald A, Noll DC, et al. Selective deficits in prefrontal cortex function in medication-naïve patients with schizophrenia. *Archives of General Psychiatry* 2001;58:280–288. [PubMed: 11231835]
- Chao LL, Nielsen-Bohman L, Knight RT. Auditory event-related potentials dissociate early and late memory processes. *Electroencephalography and clinical Neurophysiology* 1995;96:157–168. [PubMed: 7535221]
- Chen Y, Bressler SL, Knuth KH, Truccolo WA, Ding M. Stochastic modeling of neurobiological time series: power, coherence, Granger causality, and separation of evoked responses from ongoing activity. *Chaos* 2006;16:026113. [PubMed: 16822045]
- Cohen JD, Servan-Schreiber D. Context, cortex, and dopamine: a connectionist approach to behavior and biology in schizophrenia. *Psychological Review* 1992;99:45–77. [PubMed: 1546118]
- Donchin E, Coles MGH. Is the P300 component a manifestation of context updating? *Behavioral and Brain Sciences* 1988;11:357–374.
- Duncan-Johnson CC. P300 latency: a new metric of information processing. *Psychophysiology* 1981;18:207–215. [PubMed: 7291436]
- Duncan-Johnson CC, Donchin E. The P300 component of the event-related brain potential as an index of information processing. *Biological Psychology* 1982;14:1–52. [PubMed: 6809064]
- Ford JM, Duncan-Johnson CC, Pfefferbaum A, Kopell BS. Expectancy for events in old age: stimulus sequence effects on P300 and reaction time. *Journal of Gerontology* 1982;37:696–704. [PubMed: 7130643]
- Fowler B, Kelso B, Landlot J, Porlier G. The effects of nitrous oxide on P300 and reaction time. *Electroencephalography and clinical Neurophysiology* 1988;69:171–178. [PubMed: 2446836]
- Fowler B, Mitchell I. Biological determinants of P300: the effects of a barbiturate on latency and amplitude. *Biological Psychology* 1997;46:113–124. [PubMed: 9288409]
- Frodl-Bauch T, Gallinat J, Meisenzahl EV, Möller HJ, Hegerl U. P300 subcomponents reflect different aspects of psychopathology in schizophrenia. *Biological Psychiatry* 1999;45:116–126. [PubMed: 9894583]
- Hillyard SA, Kutas M. Electrophysiology of cognitive processing. *Annual Review of Psychology* 1983;34:33–61.
- Hillyard SA, Squires KC, Bauer JW, Lindsay PH. Evoked potential correlates of auditory signal detection. *Science* 1971;172:1357–1360. [PubMed: 5580218]
- Holm A, Ranta-aho PO, Sallinen M, Karjalainen PA, Müller K. Relationship of P300 single-trial responses with reaction time and preceding stimulus sequence. *International Journal of Psychophysiology* 2006;61:244–252. [PubMed: 16364479]
- Huettel SA, Song AW, McCarthy G. Decisions under uncertainty: probabilistic context influences activation of prefrontal and parietal cortices. *The Journal of Neuroscience* 2005;25:3304–3311. [PubMed: 15800185]
- Johnson R JR. A triarchic model of P300 amplitude. *Psychophysiology* 1986;23:367–384. [PubMed: 3774922]
- Johnson R JR, Donchin E. P300 and stimulus categorization: two plus one is not so different from one plus one. *Psychophysiology* 1980;17:167–178. [PubMed: 7375618]
- Kiehl KA, Laurens KR, Duty TL, Forster BB, Liddle PF. Neural sources involved in auditory target detection and novelty processing: An event-related fMRI study. *Psychophysiology* 2001;38:133–142. [PubMed: 11321614]
- Kok A. On the utility of P3 amplitude as a measure of processing capacity. *Psychophysiology* 2001;38:557–577. [PubMed: 11352145]

- Kutas M, McCarthy G, Donchin E. Augmenting mental chronometry: the P300 as a measure of stimulus evaluation time. *Science* 1977;197:792–795. [PubMed: 887923]
- Low KA, Leaver E, Kramer AF, Fabiani M, Gratton G. Fast optical imaging of frontal cortex during active and passive oddball tasks. *Psychophysiology* 2006;43:127–136. [PubMed: 16712583]
- MacDonald AW, Carter SC, Kerns JG, Ursu S, Barch DM, Holmes AJ, et al. Specificity of prefrontal dysfunction and context processing deficits to Schizophrenia in never-medicated patients with first-episode psychosis. *American Journal of Psychiatry* 2005;162:475–484. [PubMed: 15741464]
- MacDonald AW, Cohen JD, Stenger VA, Carter CS. Dissociating the role of the dorsolateral prefrontal and anterior cingulate cortex in cognitive control. *Science* 2000;288:1835–1838. [PubMed: 10846167]
- McCarthy G, Donchin E. A metric for thought: a comparison of P300 latency and reaction time. *Science* 1981;211:77–80. [PubMed: 7444452]
- McCarthy G, Luby M, Gore J, Goldman-Rakic P. Infrequent events transiently activate human prefrontal and parietal cortex as measured by functional MRI. *Journal of Neurophysiology* 1997;77:1630–1634. [PubMed: 9084626]
- Miller EK, Cohen JD. An integrative theory of prefrontal cortex function. *Annual Review of Neuroscience* 2001;24:167–202.
- Munson R, Ruchkin DS, Ritter W, Sutton S, Squires NK. The relation of P3b to prior events and future behavior. *Biological Psychology* 1984;19:1–29. [PubMed: 6478001]
- Parasurman R, Richer F, Beatty J. Detection and recognition: concurrent processes in perception. *Perception & Psychophysics* 1982;31:1–12. [PubMed: 7070933]
- Polich J. Overview of P3a and P3b. In: Polich, J., editor. *Detection of change: event-related potential and fMRI findings*. Kluwer Academic Press; Boston: 2003. p. 83-98.
- Polich J, Bondurant T. P300 sequence effects, probability, and interstimulus interval. *Physiology & Behavior* 1997;61:843–849. [PubMed: 9177555]
- Polich J, Criado JR. Neuropsychological and neuropharmacology of P3a and P3b. *International Journal of Psychophysiology* 2006;60:172–185. [PubMed: 16510201]
- Poulsen C, Luu P, Davey C, Tucker DM. Dynamics of task sets: evidence from dense-array event-related potentials. *Cognitive Brain Research* 2005;24:133–154. [PubMed: 15922166]
- Sawaki R, Katayama J. Stimulus context determines whether non-target stimuli are processed as task-relevant or distractor information. *Clinical Neurophysiology* 2006;117:2532–2539. [PubMed: 17005448]
- Squires KC, Hillyard SA, Lindsay PH. Vertex potentials evoked during auditory signal detection: relation to decision criteria. *Perception & Psychophysics* 1973;14:265–272.
- Squires KC, Squires NK, Hillyard SA. Decision-related cortical potentials during an auditory signal detection task with cued observation intervals. *Journal of Experimental Psychology: Human Perception and Performance* 1975;1:268–279. [PubMed: 1202150]
- Squires KC, Wickens C, Squires NK, Donchin E. The effect of stimulus sequence on the waveform of the cortical event-related potential. *Science* 1976;193:1142–1146. [PubMed: 959831]
- Sutton S, Braren M, Zubin J, John ER. Evoked-potential correlates of stimulus uncertainty. *Science* 1965;150:1187–1188. [PubMed: 5852977]
- Sutton S, Tueting P, Zubin J, John ER. Information delivery and the sensory evoked potential. *Science* 1967;155:1436–1439. [PubMed: 6018511]
- Suwazano S, Machado L, Knight RT. Predictive value of novel stimuli modifies visual event-related potentials and behavior. *Clinical Neurophysiology* 2000;111:29–39. [PubMed: 10656508]
- Truccolo WA, Ding M, Knuth KH, Nakamura R, Bressler SL. Trial-to-trial variability of cortical evoked responses: implications for the analysis of functional connectivity. *Clinical Neurophysiology* 2002;113:206–226. [PubMed: 11856626]
- Verleger R. Event-related potentials and cognition: a critique of the context updating hypothesis and an alternative interpretation of P3. *Behavioral and Brain Sciences* 1988;11:343–427.
- Verleger R. On the utility of P3 latency as an index of mental chronometry. *Psychophysiology* 1997;34:131–156. [PubMed: 9090263]

- Walter WG, Cooper R, Aldridge CVJ, McCallum WC, Winter AL. Contingent negative variation: an electric sign of sensorimotor association and expectancy in the human brain. *Nature* 1964;203:380–384. [PubMed: 14197376]
- Wilkinson RT, Morlock H. Auditory evoked response and reaction time. *Electroencephalography and Clinical Neurophysiology* 1967;23:50–56. [PubMed: 4165560]
- Xu L, Stoica P, Li J, Bressler SL, Shao X, Ding M. ASEO: A method for the simultaneous estimation of single-trial event-related potentials and ongoing brain activities. *IEEE Transactions on Biomedical Engineering*. in press. 10.1109/TBME.2007.901025

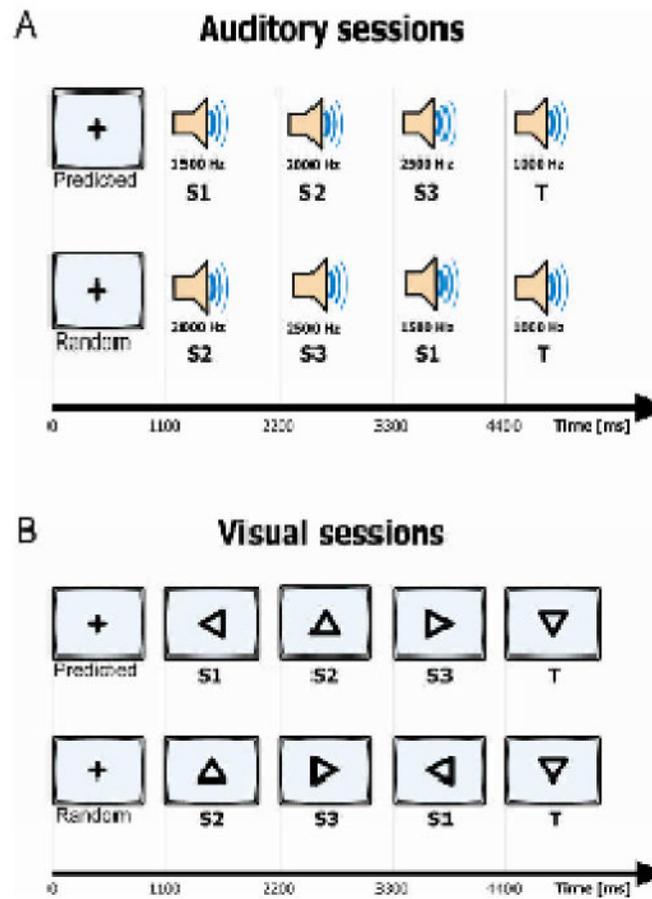


Figure 1. Auditory (A) and visual (B) sessions. Sequences of standards S1, S2 and S3 with a predicted sequence (top) and in randomized order (bottom) preceding the target (T). Stimuli presented centrally. Inter-trial intervals, including duration of stimulus presentation (100ms) are displayed.

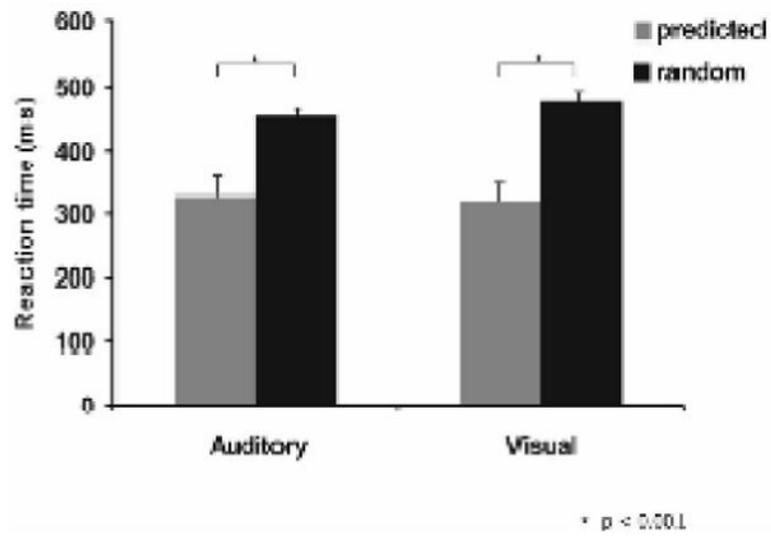


Figure 2. Reaction times for predicted and random targets in the auditory and visual modalities. Bars = standard errors of mean.

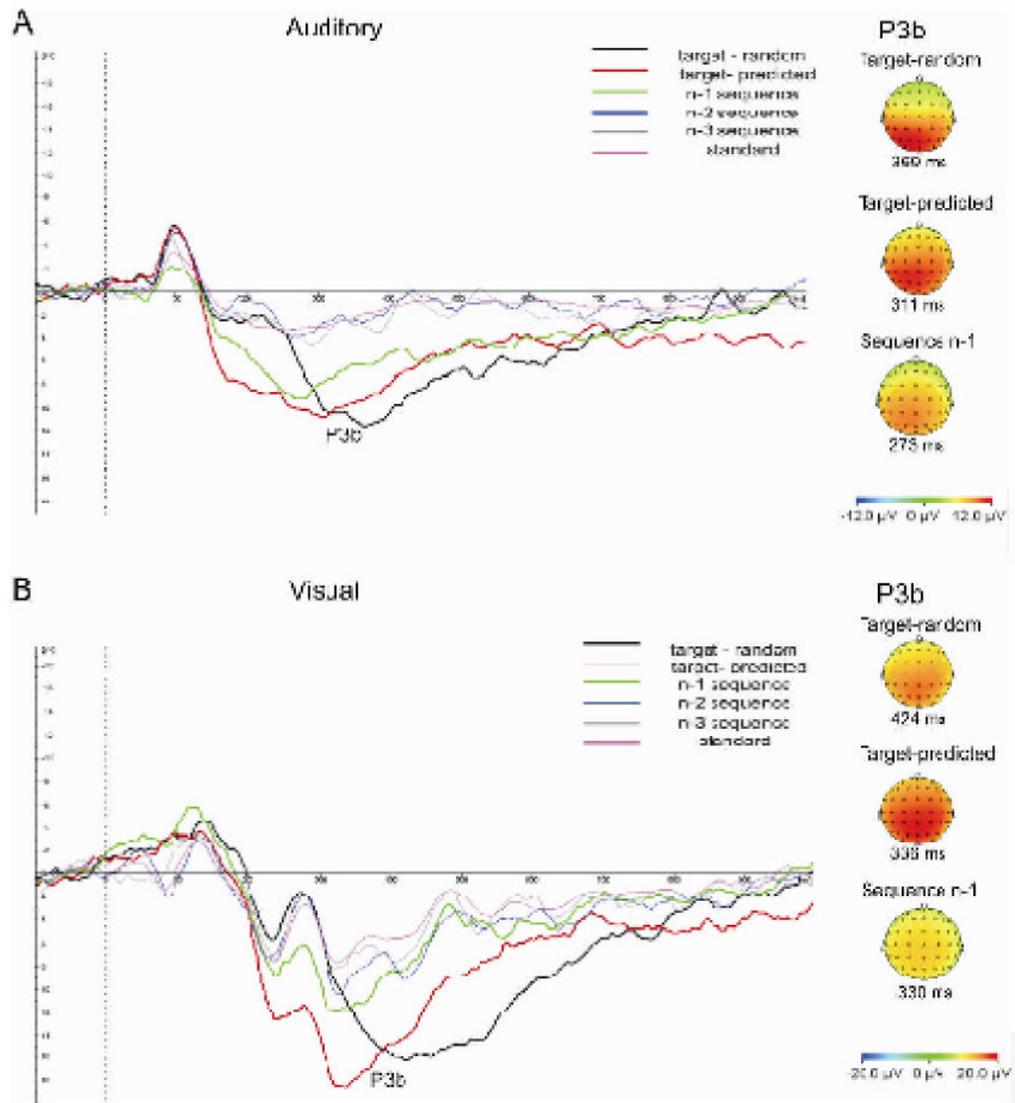


Figure 3. Grand average ($n=12$) at Pz for the 6 conditions: targets after non predictive (random) and predictive sequences (predicted), the three standards comprising the predicting sequence (n-3, n-2, n-1) and random preceding standards (standards) for auditory (**A**) and visual (**B**) modalities. Topographical maps for the peak P3b are shown for random, predicted and n-1 conditions.

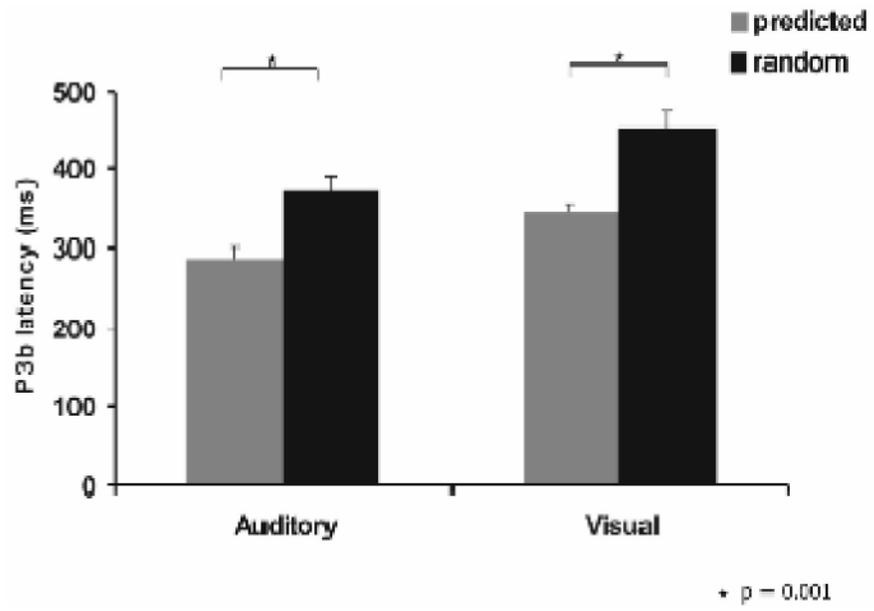


Figure 4. P3b peak latency at Pz for predicted and random targets in the auditory and visual modalities. Bars = standard errors of mean.

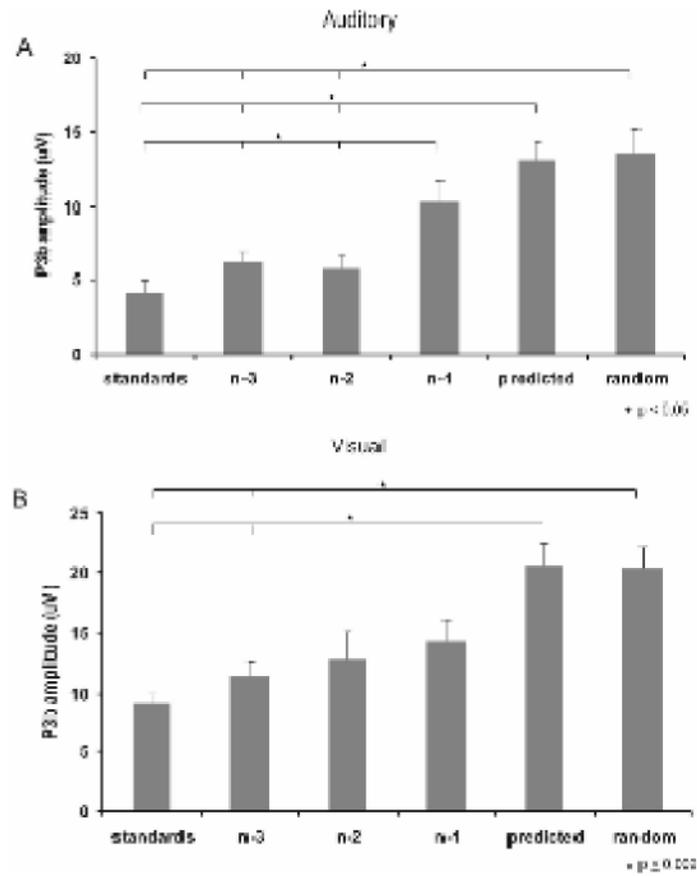


Figure 5. P3b peak amplitude for the six conditions: targets after non predictive (random) and predictive sequences (predicted), the three standards comprising the predicting sequence (n-3, n-2, n-1) and random preceding standards (standards) in the auditory (A) and visual (B) modalities. Bars = standard errors of mean.

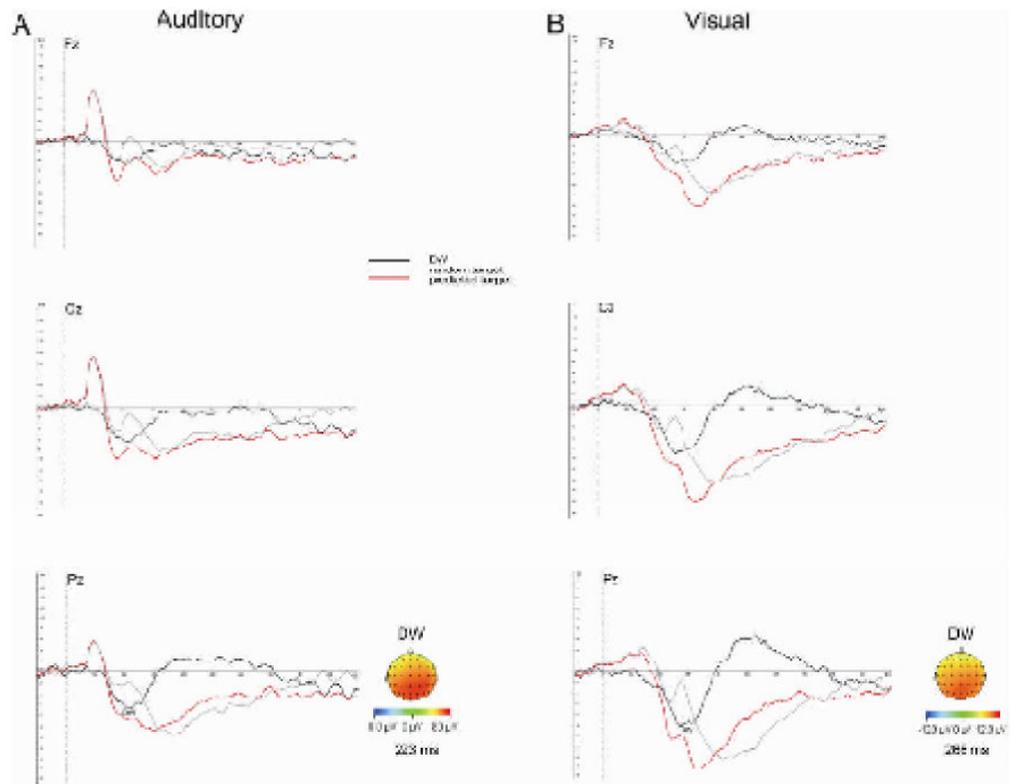


Figure 6. Grand average ($n=12$) for the difference wave (DW) between predicted and random targets at electrode sites Fz, Cz and Pz in the auditory (A) and visual (B) modalities. Topographical maps for the peak DW at Pz are displayed.

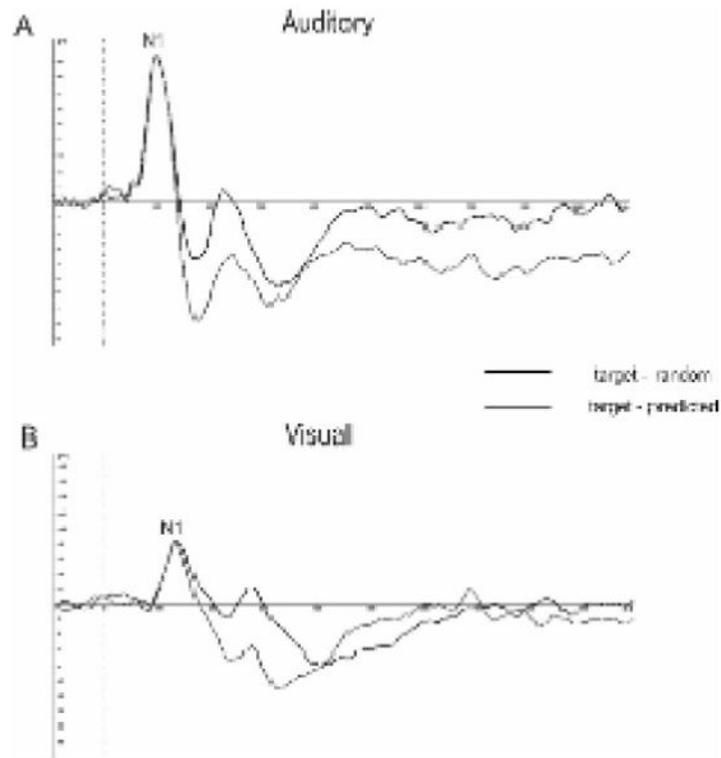


Figure 7. Grand average ($n=12$) for predicted and random targets at Fz in the auditory modality (A) and at PO8 in the visual modality (B), illustrating that N1 is not different in the two target conditions.

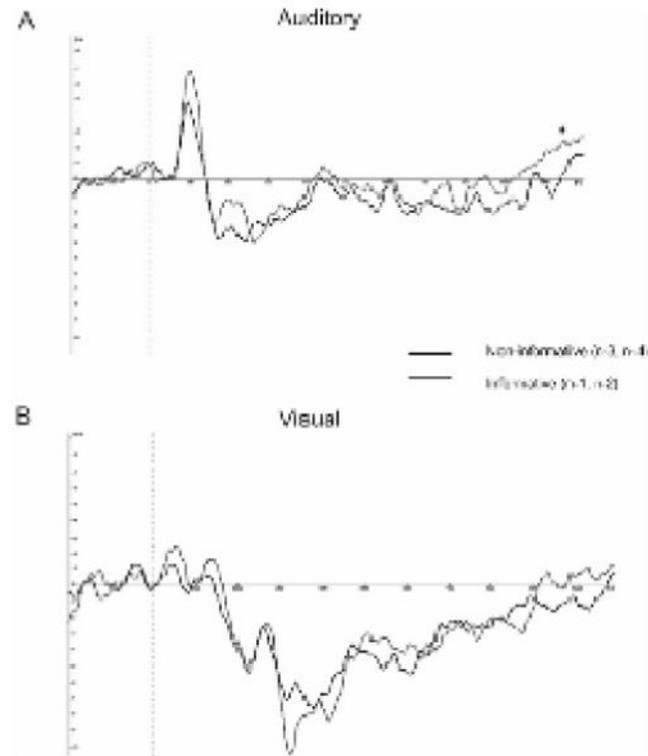


Figure 8.

Grand average ($n=12$) for standards containing predictive information (n-1 and n-2, informative condition) and for standards containing no predictive information (n-3,n-4, non-informative condition) regarding the subsequent target at CPz in the auditory modality (A) and at Cz in the visual modality (B). These electrodes showed the greatest change in mean CNV amplitude between 900 and 1100 ms post-stimulus presentation, with significance difference ($p<0.05$, indicated by the star) in the auditory modality.

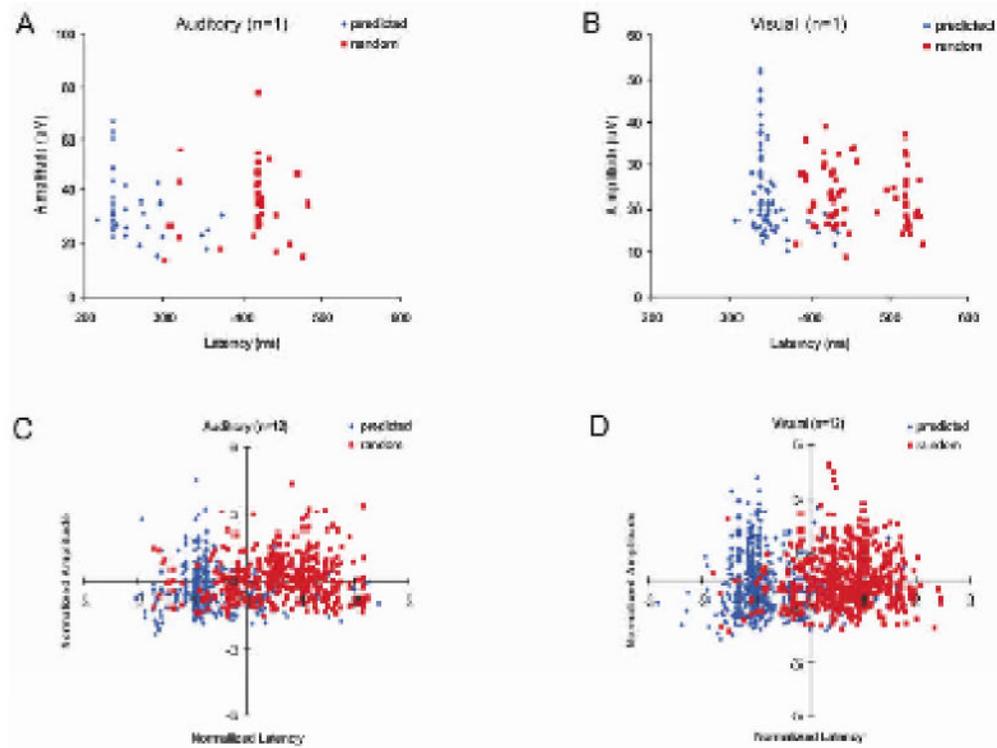


Figure 9. Single-trial P3b amplitude and latencies for predicted and random targets are plotted for auditory (A) and visual (B) modalities (n=1). Normalized values (z-transformed) of P3b amplitude and latency of predicted and random targets in all 12 subjects plotted for the auditory (C) and visual (D) modalities. Note that in all the plots latency is shorter, while amplitude is similar for predicted vs. random targets.