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Preventing distraction: Assessing stimulus-specific and general effects of the predictive cueing of deviant auditory events

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Abstract

Rare irregular sounds (deviants) embedded into a regular sound sequence have large potential to draw attention to themselves (distraction). It has been previously shown that distraction, as manifested by behavioral response delay, and the P3a and reorienting negativity (RON) event-related potentials, could be reduced when the forthcoming deviant was signaled by visual cues preceding the sounds. In the present study, we investigated the type of information used in the prevention of distraction by manipulating the information content of the visual cues preceding the sounds. Cues could signal the specific variant of the forthcoming deviant, or they could just signal that the next tone was a deviant. We found that stimulus-specific cue information was used in reducing distraction. The results also suggest that early P3a and RON index processes related to the specific deviating stimulus feature, whereas late P3a reflects a general distraction-related process.

Keywords

Attention; Distraction; Event related potentials (ERP); P3a; Reorienting negativity (RON); Predictability; Cueing

1. Introduction

Human information processing capacity is limited. In sensory information processing tasks, prioritizing the processing of task-relevant sensory information (*selective attention*) is of high importance, because failure to suppress task-irrelevant information (*distraction*) may lead to brief decrease in performance necessitating the engagement of compensatory processes. On the other hand, being distracted may provide an opportunity to reevaluate a situation and re-assess goal priorities. For example, it is well worth being distracted by the fire alarm even if the paper we read is highly interesting. Under normal circumstances, there is a balance between maintaining the selective attentional set and processing distracting stimuli. This balance can be affected in many ways: for example, by information signaling forthcoming distracting events. In a previous study Sussman et al. (2003) showed that such predictive cues are utilized by the brain to prevent or reduce the effects of potentially distracting stimuli. Here we report the results of experiments investigating how predictive

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cues strengthen the maintenance of the selective attention set, thus guarding against distraction by task-irrelevant auditory events.

Distraction-related processing can be described in the framework of a three-stage model (see e.g., Escera and Corral, 2007; Horváth et al., 2008). According to this model, incoming stimuli are processed by a sensory filter (*first stage*), which “flags” infrequent, unpredictable sensory events as being potentially informative, and initiates their attentional processing. That is, such events may trigger an involuntary attention switch (*second stage*). Following attention switching, a number of processes take place (*third stage*). As a result of the evaluation of the distracting event, task or goal priorities may change. If not, that is, performing the current task is continued, then the task-optimal attention set is restored (reorientation).

This three-stage model is largely based on studies presenting oddball sequences and measuring event-related brain potentials (ERPs). In the oddball paradigm, infrequent, unpredictably occurring stimuli (*deviants*) are embedded in a regular stimulus sequence (items of which are termed *standards*). Differences in behavioral or physiological responses to deviants and standards are assumed to reflect processes described in the three-stage model. ERP responses associated with the first stage of the model comprise of a first-order change detection process, which is reflected by the modulation of the modality-specific N1 component, peaking around 100 ms after change onset (for a review, see Näätänen and Picton, 1987) and a deviance-detection process working on the basis of regularities extracted from the previous stimulation. The latter is indexed by the mismatch negativity (MMN), peaking 100–200 ms after deviance onset (Näätänen et al., 1978; for a process-oriented review, see Winkler, 2007). Either one of these processes may initiate an involuntary attention switch assumed to be reflected by the modality-independent, fronto-central P3a (or novelty P3, see Friedman et al., 2001; Polich, 2007). When participants attend the stimuli, both target and non target deviants also often elicit a central negativity (N2b; Näätänen and Gaillard, 1983; for a review, see Folstein and van Petten, 2008). N2b is assumed to reflect the controlled registration of the infrequent task-relevant event (Ritter et al., 1992). For the third stage of the model, the correspondence between cognitive functions and ERP components is less well studied. Restoration of the task-optimal attentional set is thought to be reflected, at least in part, by the modality-independent, reorienting negativity (RON), which peaks fronto-centrally, 400–600 ms after the onset of change/deviation (Berti and Schröger, 2001; Schröger et al., 2000; Schröger and Wolff, 1998b). However, RON may also reflect some adjustments to response- and decision-related aspects of goal-directed behavior (Berti, 2008a,b; Escera et al., 2001). Finally, the P3b component, which typically peaks parietally, probably reflects the maintenance of the task-related stimulus context information in working memory or decision-related processes regarding stimulus-response associations (Donchin and Coles, 1988; Polich, 2007; but see Verleger, 1988, 2008).

Sussman, et al. (2003, see also Wetzel and Schröger, 2007) showed that some of the distraction-related processes delineated above can be influenced by information predicting a forthcoming deviant. On each trial, participants discriminated short and long sounds presented with 50% probability, each. Deviants presented 10% of the time differed from the standard sounds in the task-irrelevant pitch feature. In this paradigm (Schröger and Wolff, 1998a), behavioral and physiological response differences between deviants and standards are assumed to reflect processes related to distraction. Sussman et al. (2003) presented a visual cue –one of two possible stimuli – before each auditory stimulus, and manipulated the predictive value of the cue across conditions. In the Predictable condition, there was a one-to-one correspondence between the two visual cue stimuli and the two sound pitches so that the visual stimulus signaled the type of the next sound. In the Unpredictable condition, the two visual stimuli and the two pitches were presented independently of each other so that the

visual stimulus was not predictive with respect to the type of sound. In the Predictable condition, no significant P3a or RON ERP components were elicited by deviants, and no significant behavioral distraction-related response delays were observed, in contrast with the Unpredictable condition, in which both P3a and RON, and a response delay were observed. However, the ERP responses linked with first-stage processes (N1 and MMN) were not affected. Thus, whereas sound change and acoustic deviation was detected irrespective of the predictive value of the visual cue, information about the timing and quality of the infrequent task-irrelevant event reduced the distraction caused by this event. Assuming the above-described interpretation of P3a and RON, predictive information reduced the tendency for switching attention to the task-irrelevant deviant sound-feature and, possibly as a consequence, reorientation was less often needed.

Whereas the Sussman et al. (2003) study showed which stages can be influenced by the information provided by predictive cues, it did not clarify what aspect of the cue information was utilized in preventing/reducing distraction. There are at least two ways in which information about a forthcoming distractor may provide a means to prevent distraction.

1. Information regarding the probability of the forthcoming stimulus (i.e., whether or not a tone will carry a rare task-irrelevant feature) may be used to enhance focusing on the set of task-relevant stimulus-features, thereby *generally* impacting the processing of any incoming task-irrelevant information. Indeed, it has been suggested that signals originating from the first stage may have to reach a variable threshold before they can trigger an involuntary attention shift (Schröger, 1997). The existence of such a threshold is supported by the fact that measures of distraction seem to correlate with the magnitude of unexpected sensory change. That is, more salient changes result in higher measures of distraction in oddball paradigms (see e.g. Berti et al., 2004; Escera et al., 2001; Yago et al., 2001; but see Horváth et al., 2008 for constraints on this correlation). It has been suggested that distractors appearing within the focus of attention may be more effective than those outside the focus (Schröger and Wolff, 1998a), and voluntary allocation of attention may be the primary way to influence this threshold.
2. *Stimulus-specific* information about the distractor stimulus (e.g., its pitch) may be used to prevent distraction. Such information may be used for example, to inhibit the processing of the specific information or to adapt the selective attentional set to accommodate the predicted stimulus; for example, set up a response association for a high tone of short duration.

The aim of the current study was to specify whether in preventing/reducing distraction, the brain utilizes the general or specific information (as defined above) provided by the predictive cue. To this end, in two experiments, we manipulated whether the visual cue conveyed information only regarding the probability (*general* information) or also the *specific* make-up of the forthcoming stimulus. Similarly to Sussman et al.'s (2003) study, in both experiments, a visual cue was presented before each sound, and the predictive value of the visual cue was manipulated across the conditions. In the Fully Predictable conditions, there was a one-to-one correspondence between the visual cue stimuli and the possible pitches which the forthcoming sound could assume. In the Predictable Sound Probability conditions, the cue signaled only whether the forthcoming sound was a deviant or a standard, but it did not specify the pitch of the deviant. In the Unpredictable conditions, there was no correspondence between the visual cue stimuli and the pitch of the subsequent sound. In order to separate the general and the stimulus-specific cueing effects, in addition to the Single deviant conditions, which replicated Sussman et al.'s (2003) conditions, we also presented Multiple Deviants conditions in which cues could be uninformative regarding the forthcoming tone (Unpredictable condition) or could signal either only the probability of

the subsequent sound (Predictable Sound Probability condition) or also the specific pitch of the subsequent sound (Fully Predictable condition). Experiment 2 was designed to separate alternative explanations accounting for the results of Experiment 1. We start with the details of Experiment 1, and then provide the rationale and hypotheses of Experiment 2 in the Discussion of the results of Experiment 1.

In addition to replicating the results of Sussman et al. (2003) (presented in detail as Supplementary Material), we tested the following hypotheses in Experiment 1.

The *stimulus-specific cue information hypothesis* suggests that the specific information about the forthcoming deviant sound is utilized. Thus it should provide a more efficient way of preventing distraction than a general cue can. Therefore, distraction measures should be smaller in the Fully Predictable than in the Predictable Sound Probability condition. It is also possible that the cue carrying only sound-probability information is not useful at all for preventing distraction. In this case, distraction-related measures should not differ from each other between the Predictable Sound Probability and the Unpredictable—Multiple Deviants condition. In contrast, if only foreknowledge regarding deviancy itself is utilized in preventing distraction, then distraction measures should not differ from each other between the Predictable Sound Probability and Fully predictable conditions.

We also hypothesized that the efficacy of the cue declines with increasing number of cue-sound pairs. This is because the cost of selecting the correct association from more alternatives may decrease the capacity for preventing distraction itself. On this hypothesis, distraction measures should be smaller in the Fully Predictable—Single Deviant than in the Fully Predictable—Multiple Deviants condition. However, before testing the effects of the number of cue-sound pairs on the efficacy of preventing distraction, we assessed the effects of the presence multiple deviants in contrast to that of a single deviant. Increased variability within a stimulus sequence may increase or reduce the effects of distractors, which in turn would confound comparisons between Single Deviant and Multiple Deviants conditions. The existence of such a context effect was tested by comparing distraction measures between the Unpredictable—Single Deviant and Unpredictable—Multiple Deviants condition. This analysis is presented in detail as Supplementary Material.

2. Experiment 1

2.1. Methods

2.1.1. Participants—Eighteen paid healthy volunteers reporting normal hearing status and with normal or corrected-to-normal vision (10 women; age 19–25 years, mean: 22 years; one left-handed) participated in the experiment. All participants gave written informed consent after the experimental procedures were explained to them. One participant's data was rejected from the analyses due to excessive artifacts resulting in the rejection of more than 80% of the trials.

2.1.2. Stimuli and procedure—The participants were seated in a comfortable chair in a well-lit, sound-attenuated room during the experiment. They were instructed to focus on a white fixation cross of $0.5^\circ \times 0.5^\circ$ extent presented over a black background at the center of the monitor screen which was placed at a distance of 150 cm in front of them. The fixation cross was present continuously during the stimulus blocks. Sequences of sinusoid tones were presented with a stimulus onset asynchrony (SOA—onset-to-onset inter-stimulus interval) of 1180 ms through a Sennheiser HD-600 headphone. The intensity of the tones was individually adjusted to 50 dB sensation level (above the hearing threshold). The duration of the tones was 100 or 200 ms equiprobably distributed across trials, including 5 ms linear rise and identical fall times. The frequency of the tones was 988 Hz (87.5% probability—

standards), 880 Hz (low deviants, two semitones; ST—lower than standards; 12.5%/6.25% in Single vs. Multiple Deviants stimulus blocks, respectively), and 1109 Hz (high deviants, two ST higher than standards; 12.5%/6.25% in Single vs. Multiple Deviants stimulus blocks, respectively). The order of the tones was random. 340 ms before the onset of each tone, a visual cue stimulus, a rectangle of $1.23^\circ \times 1.23^\circ$ size and 72 cd/m² intensity, was presented for 100 ms on the screen. This cue was presented at one of three possible locations: its center could be 1.76° below (low cue, green color), 1.76° above (high cue; green color), or at the center of the fixation cross (standard cue; white color).

Experiment 1 comprised of five stimulus conditions. In the two Single Deviant conditions, deviants of one pitch (either high or low, delivered in different stimulus blocks) were presented amongst the standard tones, whereas in the three Multiple Deviants conditions high and low deviants were equiprobably presented in the stimulus sequences. In both the Single and the Multiple Deviants Fully Predictable conditions high deviants were preceded by the high cue, low deviants by the low cue, and standards by the standard cue. In both the Single and the Multiple Deviants Unpredictable conditions cue probabilities matched those of the corresponding tones (87.5% for standard, 12.5/6.25 for deviant cues in the Single and Multiple Deviants conditions, respectively) but the order of the tones and the cues were separately randomized. In the Multiple Deviants Predictable Sound Probability condition, standards were always preceded by the standard cue, whereas deviants were preceded by the low or the high cue with equal probability irrespective of the pitch of the deviant tone. Each condition consisted of four stimulus blocks with 152 trials. The first two trials of each stimulus block were a short and a long standard tone, which provided an example of the two different tone durations to be discriminated. The order of the conditions was separately randomized for each participant. In the Single Deviant conditions, stimulus blocks containing the same type of deviant were presented successively. Stimulus blocks were separated by short breaks as needed. A longer break was inserted between two conditions at about the middle of the experimental session.

Participants were instructed to press a response button held in their dominant hand for every long tone irrespective of any frequency changes, and to withhold responses for short tones; a Go-NoGo task. To eliminate the need to recognize cue-sound relationships on their own, participants were explicitly informed about the relationship between the visual cues and the sounds before each stimulus block. The instructions also emphasized that the visual cue may help to respond faster even if there was no predictive relationship between the cue position and tone pitch. To motivate accurate task performance, a small bonus payment was given for each stimulus block in which the participants correct response rate exceeded 90%, up to a maximal ca. 80% premium in addition to the guaranteed fee for participation. Breaks were provided during the test session as needed.

2.1.3. EEG recording—EEG was recorded using Ag/AgCl electrodes by a Neuroscan Synamps 2 amplifier with 250 Hz sampling rate, filtered between the DC-40 Hz range, from the scalp-locations FP1, FP2, F7, F3, Fz, F4, F8, C3, Cz, C4, T3, T4, T7, T8, P3, Pz, P4, O1, O2. Electrodes were also placed at the mastoids (left: Lm and right: Rm). The reference electrode was attached to the tip of the nose. Eye-movements were recorded with a three-electrode setup described by Schlögl et al. (2007), which was used for offline eye-movement correction. For this purpose, an additional two-minutes-long EEG-recording was taken prior to the start of the stimulation, during which participants performed various eye-movement patterns as described by Schlögl et al. (2007). Following eye-movement correction, EEG was band-pass filtered between 1 and 16 Hz. 1180 ms long epochs corresponding to deviant and standard trials, pooled across stimulus durations, were extracted including a 100 ms pre-cue interval, and deviant-minus-standard difference waveforms were calculated. For assessing Condition effects on visual cue-related ERPs, deviant-cue-minus-standard-cue

differences were also calculated. Epochs corresponding to the first two trials of each stimulus block and epochs with a signal amplitude range exceeding 100 μV on any channel were excluded from the analyses.

2.1.4. Statistical analyses—Only correct behavioral responses made in the interval 150–800 ms from sound onset were included in the analysis of the behavioral responses. Because of the different number of deviant and standard trials, the number of hits, false alarms, misses, and correct rejections were proportionally scaled down by the ratio of the deviant and standard trials, and rounded to the nearest integer. Hit rates of 1 and false alarm rates of zero were adjusted to $1 - (1/2N)$ and $1/2N$, respectively, where N is the number of targets (i.e., long stimuli, see Macmillan and Creelman, 1991). Reaction times and d' values were analyzed in Condition $\times$ Stimulus repeated-measures ANOVAs.

ERP components were visually identified in the group-average deviant-minus-standard difference waveforms. Mean amplitudes were measured in 40 ms long intervals centered on the group-average component peaks and referred to average voltage in the pre-cue interval. The actual measurement ranges from the tone onset were: N1 (96–136 ms), N2 (184–224 ms), P3a (290–330 ms), LN1 (356–396 ms), and LN2 (452–492 ms). Amplitude measurements were submitted to repeated-measures ANOVAs using Electrode (Fz, Cz, Pz, O and M, where O is the average of O1 and O2, and M is the average of Lm and Rm), Stimulus (deviant vs. standard) and Condition; different tests contrasted different sets of conditions as factors (see below). Partial eta-squares are reported for each significant effect. To correct for violations of sphericity, Greenhouse-Geisser correction was applied when appropriate. The epsilon values and uncorrected degrees of freedom are reported, with corrected p -values. All analyses were conducted using R (R Development Core Team, 2009).

Four lines of analyses were calculated, differing only in the levels of the Condition factor. In each statistical analysis, the focus was on testing for an interaction between the Condition and the Stimulus factors, because significant interactions of this type indicate different distraction-related responses between conditions. In order to keep the description concise, we do not discuss the other significant effects, such as the main effects of the three factors as well as interactions not including both the Condition and the Stimulus factors, although these are also shown in the corresponding tables. For assessing the processing of the visual cues, analyses of the same structure as described above were also conducted for the cue-related ERPs. These analyses are presented as Supplementary Material.

2.2. Results

Group average reaction times and d' values are presented in Fig. 1. Group average ERPs elicited by deviant and standard trials and corresponding deviant-minus-standard difference waveforms are presented in Fig. 2.

In general, deviant and standard tones elicited similar ERP responses: A centrally maximal negativity peaking at 116 ms was followed by a widely distributed negativity in the 200–300 ms range and a slow wide positivity peaking between 300 and 700 ms. The deviant-minus-standard difference waveforms, however, exhibited certain differences between conditions. Whereas a fronto-central negativity peaking at 120 ms, identified as an N1, could be observed in all conditions, a second centrally maximal negative waveform peaking at 204 ms (N2b) was only present in the Unpredictable conditions. Although we assume that MMN probably also contributed to one or both of these negativities, the current paradigm did not allow us to provide an unbiased estimate of this contribution. A fronto-centrally distributed positivity peaking at about 310 ms (P3a) was discernible in each condition. This component was most prominent in the Unpredictable conditions. Two late negativities peaked at 376

and 472 ms. Whereas the first of the two peaks is most prominent in the Fully Predictable and Predictable Sound Probability conditions, the second late negativity primarily characterizes the responses obtained in the Unpredictable conditions. Because it appears that these late negativities reflect overlapping ERP components (RON and P3b), we refer to them descriptively as LN1 and LN2.

The N1/MMN and N2b components could be readily observed in the deviant-minus-standard ERP waveforms in the Unpredictable conditions. However, most of the comparisons testing our hypotheses include conditions in which the N1/MMN and N2b components were apparently overlapped by ERPs elicited by the visual cue. Therefore, we do not interpret the effects on these components. Detailed analyses of the amplitude patterns for these components are presented as Supplementary Material.

An overview of the statistical test-results is presented in Table 1.

2.2.1. Replication of the results of Sussman et al. (2003)—Single Deviant conditions—In these analyses, we tested the cueing effects found by Sussman et al. (2003) by comparing the responses obtained in the two Single Deviant conditions (Fully Predictable vs. Unpredictable). ERPs and the corresponding mean amplitudes are presented in the first two columns of Figs. 2 and 3, respectively. The detailed analyses of the behavioral responses and the ANOVA results for the measured ERP amplitudes are presented as Supplementary Material.

Full cueing of the irrelevant pitch deviance abolished the distraction-related response delay and accuracy decrease (Fig. 1) found in the Unpredictable condition. ERP effects revealed further effects of this cueing. No significant P3a was elicited in the Fully Predictable condition, which also yielded a higher amplitude widely distributed negative deviant-minus-standard difference in the LN 1 interval than the Unpredictable condition. In the LN 2 interval, the amplitude was lower for deviants than for standards. The decrement was widely distributed in the Unpredictable condition, whereas it mainly occurred over occipito-parietal areas in the Fully Predictable condition. These results are compatible with the notion that a fronto-central negativity overlaps a negative, parietal P3b-effect in the Unpredictable, but not in the Fully Predictable condition. A possible interpretation of this effect is that a RON component of higher amplitude was elicited in the Unpredictable than in the Fully Predictable condition (cf. Section 2.3).

2.2.2. General effects of the context—comparing the Unpredictable Single and the Multiple Deviant conditions—In this section, we tested the general effects of the presence of multiple deviants in the sequences by comparing the behavioral and ERP responses between the Unpredictable—Single Deviant and Unpredictable—Multiple Deviants conditions. ERPs and the corresponding mean amplitudes are presented in the first and third columns of Figs. 2 and 3, respectively. The detailed results of the analyses of the behavioral and ERP responses are presented as Supplementary Material.

In the Unpredictable conditions, the deviant stimuli elicited the expected pattern of N1/MMN, N2b, P3a and RON components, with no significant amplitude differences related to the number of different deviants occurring in the stimulus sequences. The only component reacting differentially to the number of deviants was the deviance-related P3b reduction, which was smaller in the Unpredictable Multiple than in the Single Deviant condition.

2.2.3. Interaction between the context and the cues—comparing the Fully Predictable Single and the Multiple Deviant conditions—In this section, we checked whether the number of different deviants in the sequence interacted with the effects

of the fully predicting cue by comparing the behavioral and ERP responses in the Fully Predictable Single and Multiple Deviants conditions. The relevant ERPs and the corresponding mean amplitudes are presented in the second and fifth columns of Figs. 2 and 3, respectively. The detailed ANOVA results for the measured ERP amplitudes are presented in Table 2.

2.2.3.1. Behavioral responses: The ANOVA of the reaction times in the Predictable conditions showed no significant effects. The ANOVA of the d' values showed a Stimulus main effect: $F(1,16) = 7.58, \eta_p^2 = .32, p < .05$, indicating a significantly lower d' value on deviant than on standard trials.

2.2.3.2. ERPs: The ANOVAs of the ERP amplitudes (Figs. 2 and 3, second and fifth columns, Table 2) showed no effects involving both Condition and Stimulus factors, indicating that the efficacy of cues did not significantly differ between the two Fully Predictable conditions.

2.2.4. Effects of the predictive cue information—comparing the Fully Predictable, Predictable Sound Probability, and Unpredictable Multiple Deviant conditions—In this section, we tested whether or not stimulus-specific cueing information was a necessary prerequisite of the previously observed cueing effects. We compared responses between the Fully Predictable, Predictable Sound Probability, and Unpredictable Multiple Deviants conditions. The relevant ERPs and the corresponding mean amplitudes are presented in the third, fourth and fifth columns of Figs. 2 and 3, respectively. The detailed ANOVA results for the measured ERP amplitudes are presented in Table 3.

2.2.4.1. Behavioral responses: The ANOVA of the reaction times in the Multiple Deviants conditions showed a Condition main effect: $F(2,32) = 3.38, \varepsilon = .96, \eta_p^2 = .17, p < .05$; a main effect of Stimulus: $F(1,16) = 9.10, \eta_p^2 = .36, p < .01$; and a Condition $\times$ Stimulus interaction: $F(2,32) = 5.14, \varepsilon = .96, \eta_p^2 = .24, p < .05$. Student's t -tests showed significantly slower response on deviant than on standard trials in the Unpredictable ($t[16] = 3.94, p < .01, 427$ ms vs. 400 ms), and the Predictable Sound Probability ($t[16] = 3.30, p < .01, 404$ ms vs. 390 ms) but not in the Fully Predictable condition (400 ms vs. 395 ms). Pair-wise comparisons of the deviant-minus-standard reaction time differences showed a significant difference between the Fully Predictable and the Unpredictable condition only ($t[16] = 3.50, p < .01$).

The ANOVA of d^3 s showed a Stimulus main effect: $F(1,16) = 19.58, \eta_p^2 = .55, p < .001$, indicating a lower performance on deviant than on standard trials.

2.2.4.2. ERPs: The ANOVA showed significant interactions including both the Condition and the Stimulus factor in all but the N1 interval (Table 3).

The significant Condition $\times$ Stimulus interaction found for the P3a interval was resolved by comparing the across-electrodes averaged deviant-minus-standard difference amplitudes between pairs of conditions, which showed a significant difference between Unpredictable and Fully Predictable conditions only ($t[16] = 2.25, p < .05$), indicating a more positive difference amplitude in the Unpredictable condition.

The significant Condition $\times$ Stimulus interaction found for the LN 1 interval was resolved by comparing across-electrodes averaged deviant-minus-standard difference amplitudes between pairs of conditions, which showed a significant difference between Unpredictable

and Fully Predictable conditions only ($t[16] = 2.38, p < .05$), indicating a more negative difference amplitude in the Fully Predictable condition.

The significant three-way interaction found for the LN 2 interval was resolved by one-way Condition ANOVAs of the deviant-minus-standard difference amplitudes, separately at the five levels of Electrode. Significant effects were only found at Fz ($F(2,32) = 10.77, \eta_p^2 = .40, p < .001$) and Cz: ($F(2,32) = 5.86, \eta_p^2 = .27, p < .01$). Student's t -tests between conditions conducted at Fz and Cz indicated that the difference amplitude was higher (more negative) in the Unpredictable than in the other two conditions for both electrodes (at Fz: $t[16] = 4.89, p < .001$ and $t[16] = 3.64, p < .01$; and at Cz: $t[16] = 2.89, p < .05$ and $t[16] = 2.69, p < .05$ for comparisons with the Predictable Sound Probability and the Fully Predictable conditions, respectively). These results suggest that a higher-amplitude fronto-central negativity (RON) was elicited in the Unpredictable than in the other two conditions.

In summary, P3a amplitude was higher in the Unpredictable than in the Fully Predictable condition. In the LN 1 interval the ERP amplitude was significantly more negative in the Fully Predictable than in the Unpredictable condition. RON amplitude was higher in the Unpredictable than in the other two conditions.

2.2.5. Visual ERPs—The analyses of the visual cue-related ERPs (see Supplementary Material) showed that visual cues were not processed significantly differently in the N1 and N2 intervals, in the different conditions (see the predictable conditions in Fig. 2). As could be expected, P3b amplitudes were higher in those conditions in which the cue predicted the occurrence of the deviant than in those in which it did not.

2.3. Discussion of the results of Experiment 1

Experiment 1 replicated the behavioral and ERP results of Sussman et al. (2003). Visual cues signaling forthcoming deviants reduced the deviance-related prolongation of the reaction time and improved the sensitivity of discrimination. The P3a and RON amplitudes were reduced in the Fully Predictable condition compared to the Unpredictable condition (Fig. 2, first and second columns). Also in the Fully Predictable condition, a widely distributed negativity of modest amplitude was present in the LN1 interval. This result was not expected. However, in retrospect, a similar negativity can also be observed in Sussman et al.'s data. This effect may be related to the lower information content of the cued distractor, which may be manifested in a lower-amplitude P3b. In the current experimental conditions, deviants elicited a *reduced* P3b in comparison to standards. Whereas it is typical to find an *enhanced* P3b in paradigms where oddball stimuli require a different response than the other stimuli (see e.g. Polich, 2007), most studies utilizing the present type of distraction paradigm did not find a P3b enhancement. Whereas a negative P3b effect was not found in most studies, it seems possible that such an effect was simply not dissociated from the also negative RON. The present study suggests that a P3b-reduction may be always present for deviants in this type of distraction paradigm, and the resulting ERP amplitude and topography reflects the interplay of the frontal RON and this parietal P3b-reduction. Although we cannot provide a detailed explanation for this P3b-reduction, a possible cause may be that in the current paradigm deviants and standards require the same responses, that is, the deviant/standard distinction is irrelevant in terms of the task.

The current results did not provide a clear answer to our main question: Whether the effects of the cue in reducing distraction are based on stimulus specific information (i.e., predicting the quality upcoming deviant sound—as in the Fully Predictable conditions) or only on information regarding the probability of the upcoming sound (as in the Predictable Sound Probability condition). These hypotheses were contrasted in the Multiple Deviants

conditions. The analyses of P3a, RON and the reaction time delay point to a clear difference between the Unpredictable and Fully Predictable conditions, however, such an unequivocal assessment of the Predictable Sound Probability condition was not warranted. Only the analysis of the RON yielded a significant result separating this condition from any of the others: the RON amplitude was significantly more negative in the Unpredictable than in the Fully Predictable and the Predictable Stimulus Probability conditions. This result suggests that foreknowledge of an upcoming rare sound, irrespective of its quality, is sufficient to reduce the distracting effect of rare stimulus events.

The second question was whether the effects of fully predictable cueing would differ when single or multiple cue-deviant pairs are presented. Presenting multiple deviants within the same context did not significantly influence the distraction-related behavioral effects. Of the ERP responses, only the deviance-related P3b-reduction was affected by the presence of multiple deviants, which was smaller in the Unpredictable—Multiple Deviants than in the Unpredictable—Single Deviant condition. Whereas the cause of this effect is unclear, this may indicate that despite being task-irrelevant, the deviant/standard distinctions may nonetheless be included into the task-related stimulus representations, which is reflected by the differential P3b-effects. That no such P3b difference was found between the Fully Predictable conditions as a function of the number of deviants fits this line of thought, because in these conditions, the visual cues may allow for a better separation of the task-irrelevant stimulus characteristics, which may lead to a task-related stimulus representation which does not include the irrelevant properties. The lack of ERP differences between the two Fully Predictable conditions suggest that the cueing effects were not modulated by the number of deviants presented in the stimulus sequence.

As was concluded above, although the results of Experiment 1 are compatible with the notion that foreknowledge of the probability of the task-irrelevant aspects of the upcoming event is a sufficient prerequisite of reducing distraction, they do not rule out the possibility that stimulus-specific preparation for an upcoming deviant event may help in dealing with multiple deviant feature-variants. It is possible that two different deviants presented in the Multiple Deviants conditions of Experiment 1 may have been insufficient to saturate the specific preparatory processes and thus these could still provide significant benefits in reducing the distracting effects of task-irrelevant deviant events. That is, due to the small number of different deviants, the observed non-specific cueing effect may actually reflect stimulus-specific preparation for two feature-variations, and not a general “narrowing” of the attentional focus. This may also explain why no significant effect of the number of cue-deviant pairs was observed in Experiment 1. Experiment 2 was designed to provide a stronger test of this possibility.

3. Experiment 2

In order to test whether stimulus-specific preparation was necessary for reducing the distracting effects of task-irrelevant stimulus events, Experiment 2 repeated all but the Fully Predictable-Multiple Deviants condition of Experiment 1 with twelve well-distinguishable deviant stimuli differing from each other in frequency.

As with Experiment 1, we tested whether the results of Sussman et al. (2003) could be reproduced. This was important, because whereas in Experiment 1 the magnitude of deviance was only 2 STs, in Experiment 2, the range varied between 6 and 12 STs.

The main comparison in Experiment 2 was between the Fully Predictable—Single Deviant and the Predictable Sound Probability—Multiple Deviants conditions. If the distracting effect of the deviants could be prevented on the basis of probability information alone, then distraction-related effects should be similar between these conditions. Larger distraction

effects in the Predictable Sound Probability—Multiple Deviants condition would suggest that stimulus-specific information is required for effectively reducing the distraction effects. Furthermore, similar responses observed in the Unpredictable—Multiple Deviants vs. Predictable Sound Probability—Multiple Deviants conditions would suggest that information regarding the probability of the upcoming sound is not sufficient for effectively reducing the distracting effects of task-irrelevant deviance.

As in Experiment 1, we tested for contextual effects on distraction, such as whether the difference in stimulus variability led to distraction effects of different magnitudes, by comparing distraction-effects between the Unpredictable—Single Deviant and —Multiple Deviants conditions. This analysis is presented in detail as Supplementary Material.

3.1. Methods

3.1.1. Participants—Sixteen paid healthy volunteers reporting normal hearing status and with normal or corrected-to-normal vision (11 women; age 19–25 years, mean: 21 years; two left-handed) participated in the experiment. All participants gave written informed consent after the experimental procedures were explained to them. None participated in Experiment 1.

3.1.2. Stimuli and procedure—Twelve different deviant tones were presented, which were 2, 4, 6, 8, 10 or 12 ST higher or lower in frequency than the standard tone, which was 988 Hz as in Experiment 1. In the Single Deviant conditions, four of these were presented in separate stimulus blocks: the ± 6 and ± 12 ST deviants. Because the duration of the Single-Deviant stimulus blocks was relatively short (4 min), we presented a short tone sequence comprising three “standard-standard-standard-deviant” cycles to familiarize participants with the tones before each stimulus block. Participants were instructed to listen carefully to these tones. They were told that these tones were going to appear in the forthcoming task-relevant tone sequence. The stimulus block then started 10–20 s following the familiarizing sequence. In the Multiple Deviants conditions, all 12 deviants were presented with equal probabilities. The visual cues were the same as in Experiment 1, except that deviant visual cues combined the high and low cues of Experiment 1: both were simultaneously shown on the screen. Experiment 2 consisted of four conditions: Unpredictable and Fully Predictable—Single Deviant and Unpredictable and Predictable Sound Probability—Multiple Deviants conditions. Each condition received four stimulus blocks of 197 trials, each. In all other respect, the experimental procedures in Experiment 2 were identical to those in Experiment 1.

3.1.3. EEG recording and statistical analyses—The EEG recording procedures and statistical analyses were identical to those in Experiment 1. The measurement ranges from the tone onset were: N1 (92–132 ms), N2 (160–200 ms), early P3a (212–252 ms), late P3a (272–312 ms), LN1 (344–384 ms), and LN2 (432–472 ms).

3.2. Results

Group average reaction times and d' values are presented in Fig. 4. Group average ERP responses elicited by deviant and standard tones together with the corresponding deviant-minus-standard difference waveforms are presented in Fig. 5.

The ERP responses elicited by deviant and standard tones, as well as the deviant-minus-standard difference waveforms were generally similar to those observed in Experiment 1. As in Experiment 1, N2b, peaking at 180 ms, was only clearly present in the Unpredictable conditions of Experiment 2. The deviant-minus-standard difference waveforms, however, exhibited certain differences between the experiments. In contrast to Experiment 1, in

Experiment 2, the tone-elicited N1, peaking at 112 ms, was much larger in amplitude in the Unpredictable than in the Fully Predictable/Predictable Sound Probability conditions. Furthermore, P3a was discernible in each condition, although it was more prominent in the Unpredictable conditions. P3a exhibited two peaks: an early peak at about 232 ms, and a late one at about 290 ms. The first peak was observable as a shoulder on the traces obtained in the Unpredictable conditions; the second peak could not be discerned in the Fully Predictable—Single Deviant condition. The late negativities, peaking at 364 and about 450 ms, were more pronounced in Experiment 2 than in Experiment 1. As in Experiment 1, in most cases, assessment of the N1/MMN and N2b components was confounded by overlapping components elicited by the visual cue, therefore these are not interpreted. Detailed analyses of these amplitude patterns are presented as Supplementary Material.

An overview of the statistical test-results is presented in Table 4.

3.2.1. Replication of the results of Sussman et al. (2003)—Single Deviant conditions—In these analyses, the Condition factor contrasted the two Single Deviant conditions (Predictable—Single Deviant vs. Unpredictable—Single Deviant). ERPs and the corresponding mean amplitudes are presented in the first two columns of Figs. 5 and 6, respectively. The detailed analyses of the behavioral responses and the ANOVA results for the measured ERP amplitudes are presented as Supplementary Material.

Full cueing of the irrelevant pitch deviance abolished the distraction-related response delay and accuracy decrease (Fig. 4) that was found in the Unpredictable condition. In the Fully Predictable condition both the early and late P3a components had larger amplitudes in the Unpredictable condition. In the Fully Predictable condition, a widely distributed deviant-minus-standard waveform was observable in the LN 1 interval, as was also found in Experiment 1. In the LN 2 interval, the Unpredictable condition yielded a larger anterior negativity, which we interpret as the RON component. RON overlapped a negative P3b-effect, which was present in both conditions.

3.2.2. General effects of the context—comparing the Unpredictable Single and the Multiple Deviant conditions—In this section, we tested the general effects of the presence of multiple deviants in the sequences by comparing the behavioral and ERP responses between the Unpredictable—Single Deviant and Unpredictable—Multiple Deviants conditions. ERPs and the corresponding mean amplitudes are presented in the first and third columns of Figs. 5 and 6, respectively. The detailed analyses of the behavioral responses and the ANOVA results for the measured ERP amplitudes are presented as Supplementary Material.

The analyses showed no significant difference between the two conditions for the P3a amplitudes. In the LN 1 interval, the deviant-minus-standard amplitude difference was more negative in the Multiple than in the Single Deviant condition. However, no significant difference was found in the LN2 interval.

3.2.3. Effects of the predictive cue information—comparing the Fully Predictable—Single Deviant and the Predictable Sound Probability—Multiple Deviants condition—In this section we tested whether or not preventing distraction required stimulus-specific cueing information. A difference in the behavioral and ERP correlates of distraction between the conditions, manifesting as significant interactions involving the Condition and the Stimulus factor, would suggest that stimulus-specific information was used. The relevant ERPs and the corresponding mean amplitudes are presented in the second and fourth columns of Figs. 5 and 6. The detailed ANOVA results for the measured ERP amplitudes are presented in Table 5.

3.2.3.1. Behavioral responses: The ANOVA of the reaction times showed a Stimulus main effect: $F(1,15) = 16.44$, $\eta_p^2 = .52$, $p < .01$, and a Condition $\times$ Stimulus interaction: $F(1,15) = 20.55$, $\eta_p^2 = .58$, $p < .001$. Student's t -tests between reaction times measured on deviant and standard trials showed a significantly slower response on deviant than on standard trials in the Predictable Sound Probability—Multiple Deviants condition ($t[15] = 5.23$, $p < .001$, 444 ms vs. 400 ms), but not in the Fully Predictable—Single Deviant condition (429 ms vs. 414 ms). The ANOVA of the d' values showed a Stimulus main effect only: $F(1,15) = 5.60$, $\eta_p^2 = .27$, $p < .05$, indicating significantly lower performance on deviant than on standard trials.

3.2.3.2. ERPs: The ANOVAs showed significant interactions including both the Condition and the Stimulus factor for all but the N2 intervals (Table 5).

To resolve the significant three-way interaction for the early and late P3a intervals, Student's t -tests of the deviant-minus-standard amplitude differences between the two conditions were calculated at each electrode. These showed higher differences in the Predictable Sound Probability—Multiple Deviants condition (early P3a: at Fz, Cz and Pz: $t[15] > 2.72$, $p < .05$; late P3a: at all but M: $t[15] > 2.45$, $p < .05$).

For the significant Condition $\times$ Stimulus interaction in the LN 1 interval, the across-electrodes averaged deviant-minus-standard difference amplitude was more negative in the Fully Predictable—Single Deviants condition ($t[15] = 2.36$, $p < .05$; $-1.94 \mu\text{V}$ vs. $-0.87 \mu\text{V}$).

To resolve the three-way interaction for the amplitudes in the LN 2 interval Student's t -tests of the deviant-minus-standard difference amplitudes between the two conditions conducted separately for each electrode showed a more negative difference amplitude at Fz ($t[15] = 3.34$, $p < .01$) in the Predictable Sound Probability—Multiple Deviants than in the Fully Predictable—Single Deviant condition.

In summary, this shows that similarly to the Unpredictable conditions, in fully/partially predictable sequences, both early and late P3a amplitudes were higher in the Predictable Sound Probability—Multiple Deviants condition. In the LN1 interval, the deviant-minus-standard difference amplitudes were more negative in the Fully Predictable—Single Deviant than in the Predictable Sound Probability condition. In contrast, RON was elicited in the Predictable Sound Probability—Multiple Deviants, but not in the Fully Predictable—Single Deviant condition.

3.2.4. Effects of partial predictive cue information—comparing the Unpredictable vs. Predictable Sound Probability—Multiple Deviants conditions

In this section we tested whether information about the within-sequence probability of the forthcoming tone was sufficient for reducing distraction. This would be manifested as a significant interaction involving both the Condition and the Stimulus factor. The relevant ERPs and the corresponding mean amplitudes are presented in the third and fourth columns of Figs. 5 and 6. The detailed ANOVA results for the measured ERP amplitudes are presented in Table 6.

3.2.4.1. Behavioral responses: The ANOVA of the reaction times yielded a Condition: $F(1,15) = 14.15$, $\eta_p^2 = .49$, $p < .01$, and a Stimulus main effect: $F(1,15) = 37.63$, $\eta_p^2 = .71$, $p < .001$, showing that responses were slower on deviant than on standard trials, and they were slower in the Unpredictable than in the Predictable Sound Probability condition. The

ANOVA of the d' values showed a Stimulus main effect: $F(1,15) = 7.77, \eta_p^2 = .34, p < .05$, indicating significantly lower performance on deviant than on standard trials.

3.2.4.2. ERPs—Interaction effects including both Condition and Stimulus factors were found in each measurement interval (Table 6).

To resolve the significant three-way interaction for the early P3a interval, Student's t -tests were conducted for the Predictable Sound Probability-minus-Unpredictable Deviants differences of the deviant-minus-standard amplitude differences between the electrodes. These showed that in the Predictable Sound Probability condition the deviant-minus-standard amplitude differences were smaller at Fz and at Pz than at the other electrodes in comparison with the Unpredictable condition, with significant differences in the Fz-Cz, Fz-M, and also in the Pz-Cz, Pz-O, Pz-M comparisons ($t[15] > 2.97, p < .01$, all).

For the significant three-way interaction in the late P3a interval, Student's t tests of the deviant-minus-standard amplitude differences between the two conditions conducted at each electrode showed more positive difference amplitudes in the Unpredictable condition at all sites ($t[15] > 3.15, p < .01$, all).

In the LN 1 interval, for which a significant Condition $\times$ Stimulus interaction was found, the across-electrodes averaged deviant-minus-standard amplitude difference was more negative in the Predictable Sound Probability than in the Unpredictable—Multiple Deviants condition ($t[15] = 3.83, p < .01$; $-0.87 \mu\text{V}$ vs. $0.65 \mu\text{V}$).

For the significant three-way interaction in the LN 2 interval, Student's t -tests of the deviant-minus-standard difference amplitudes between the two conditions conducted at each electrode showed more negative difference amplitudes at O and M ($t[15] > 2.82, p < 0.05$, all) in the Predictable Sound Probability than in the Unpredictable—Multiple Deviants condition.

In summary, the distribution of the early P3a elicited by deviants was more focal, with a maximum at Cz, in the Unpredictable than in the Predictable Sound Probability condition, where it was somewhat more widely distributed over the scalp. The amplitude of the late P3a elicited by deviants was higher in the Unpredictable than in the Predictable Sound Probability condition. The mean amplitude of the deviant-minus-standard difference measured in the LN 1 interval was higher in the Predictable Sound Probability than in the Unpredictable condition. In the LN 2 interval, the scalp distribution of the deviant-minus-standard difference was more posterior in the Predictable Sound Probability than in the Unpredictable condition.

3.2.5. Visual ERPs—Visual cues (see Supplementary Material) were processed differently in the Fully Predictable—Single Deviant and Predictable Sound Probability—Multiple Deviants conditions as reflected by the two larger early negative deviant-cue-minus-standard-cue difference waveforms (see the predictable conditions in Fig. 4). Furthermore, deviant-cue-minus-standard-cue P3b amplitudes were higher in the Fully Predictable—Single Deviant than in the other three conditions.

3.3. Discussion of the results of Experiment 2

The comparison between the Fully Predictable—Single Deviant and Unpredictable—Single Deviant conditions replicated the results of Sussman et al.'s (2003) study regarding the behavioral responses, late P3a and RON. Similarly to Experiment 1, in the Fully Predictable condition, a widely distributed, relative low-amplitude negative waveform was elicited by

deviants in the LN 1 interval, and the P3b amplitude was reduced for deviants compared with standards.

Cues predicting the probability of the forthcoming sound significantly reduced distraction. This was shown by comparison between the Unpredictable and Predictable Sound Probability—Multiple Deviants conditions. Responses were slower in the Unpredictable than in the Predictable Sound Probability condition. Furthermore, the late P3a amplitude, a prime index of distraction, was higher in the Unpredictable than in the Predictable Sound Probability condition. Whereas RON was present in both conditions, the P3b-decrement for deviants was more pronounced in the Predictable Sound Probability condition than in the Unpredictable condition.

However, cues providing information only about the probability of the upcoming sound were less effective in reducing the effects of distraction than cues fully specifying the upcoming sound. This was tested in comparisons between the Fully Predictable—Single Deviant and the Predictable Sound Probability—Multiple Deviants conditions. Participants responded slower on deviant than on standard trials in the Predictable Sound Probability—Multiple Deviants, but not in the Fully Predictable—Single Deviant condition, whereas the presence of multiple deviants did not significantly affect the distraction effect *per se*. That is, there was no interaction between the Condition and the Stimulus factors when comparing the Unpredictable conditions between Single and Multiple Deviants sequences. Furthermore, the amplitudes of the ERP correlates of distraction (the early and late P3a and RON) were higher in the Predictable Sound Probability—Multiple Deviants than in the Fully Predictable—Single Deviant condition, whereas these ERPs were not affected by the presence of multiple deviants *per se*. Again, there was no interaction between the Condition and the Stimulus factors when comparing the Unpredictable conditions between Single and Multiple Deviants sequences.

Informative deviant visual cues elicited larger early occipital negativities than non-informative ones, suggesting that the brain adapts to the predictive value of the cues. Furthermore, the P3b elicited by fully predictive deviant cues was larger than that for any other cue. This ties in well with the notion that the P3b is related to updating the information of the representation in the context (Donchin and Coles, 1988).

4. General discussion

The results of this study show that stimulus-specific information carried by predictive visual cues is utilized in reducing the effects of distracting stimulus events. Whereas specific cues of the forthcoming deviant events were more effective in reducing distraction, general, or non-specific cues about upcoming deviance also led to decreased distraction effects. Although the current results demonstrate that stimulus-specific preparation does take place in the brain (see also, Baess et al., 2009; Bendixen et al., 2009), the reduction of distraction by non-stimulus-specific cues requires explanation. It may be the result of a general mechanism temporarily “narrowing” the attentional focus (Schröger, 1997). However, it is also possible to explain it as a graded stimulus-specific preparation effect. That is, the brain may be able to prepare for a limited set of distractors in parallel. This would lead to successful distraction-prevention on a certain percentage of the trials, when the actual distractor falls within the prepared-for set. Whereas the present results are compatible with the latter hypothesis, it would be difficult to reconcile it with the results of Wetzel et al. (2009). Wetzel et al. delivered environmental sounds as distractors within a predominantly tonal sequence. Each environmental sound was presented only once during the experiment. Cueing whether the upcoming sound was tonal or environmental reduced the effects of distraction, although the cue did not specify the actual sound. Therefore, it is likely that

predictive cue information is utilized both by stimulus-specific and also by non-specific processes for preventing distraction.

4.1. ERP correlates of distraction

The present experiments also yielded findings that allow one to further specify the interpretation of the ERP components elicited in distraction paradigms. Firstly, an important dissociation between early and late P3a was found. The late P3a was present for low-magnitude (in Experiment 1) as well as high-magnitude deviants (in Experiment 2), whereas the early P3a was observable only for relatively large deviations (Experiment 2). This is in accord with previous results obtained by Escera et al. (2000) and Alho et al. (1998). The current results also demonstrated that “novelty”, qualitative deviation from the context, is not a necessary prerequisite of the elicitation of the early P3a; rather, its elicitation depends on high magnitude of featural deviation from the majority of the stimuli in the context. Furthermore, whereas early P3a was reduced when the visual stimulus fully predicted the task-irrelevant deviant event, the non-specific cue only caused some change in the scalp distribution of this component. In contrast, the amplitude of the late P3a was affected by both types of cues. This suggests that the early P3a indexes stimulus-specific processes, whereas late P3a probably reflects some more general process (cf., Escera et al., 1998; Roye et al., 2007).

Similar to the early P3a, RON amplitude was reduced only when the type of the forthcoming deviant was certain, or when the uncertainty regarding its type was relatively low. RON was reduced in all Fully Predictable conditions, and in the Predictable Sound Probability condition in which only two deviants were presented (Experiment 1), but no reduction was observed when there were twelve potential deviants and only Stimulus Probability was signaled (Experiment 2). This suggests that the process reflected by RON is engaged only when participants are unprepared for the specific distracting feature variation.

In summary, the present study provided evidence that stimulus-specific preparation made possible by predictive cueing is used to prevent distraction triggered by rare, unpredictable sounds.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi: 10.1016/j.biopsycho.2011.01.011.

Fig. 1. Group-average reaction times and d' values (with standard errors of means marked) in Experiment 1.

Fig. 2.

Group-average ERP responses elicited by the deviant and standard tones and the corresponding deviant-minus-standard difference waveforms in Experiment 1. The vertical line crossing the x axis indicates the onset of the visual cue. Tone onset is at 0 ms. Grey stripes at Cz mark the five intervals in which amplitude measurement were taken (from left to right: N1, N2, P3a, LN1, LN2).

Fig. 3. Group-average mean ERP amplitudes (and standard errors of means) for the different scalp locations, separately for the five conditions (columns) and the five measurement intervals (rows) in Experiment 1. Note the different amplitude scales in the different rows.

Fig. 4. Group-average reaction times and d' values (with standard errors of means marked) in Experiment 2.

Fig. 5.

Group-average ERP responses elicited by the deviant and standard tones and the corresponding deviant-minus-standard difference waveforms in Experiment 2. The leftmost vertical line crossing the x -axis indicates the onset of the visual cue. Tone onset is at 0 ms. Grey stripes at Cz mark the six intervals in which amplitude measurement were taken (from left to right: N1, N2, early P3a, late P3a, LN1, LN2).

Fig. 6. Group-average mean ERP amplitudes (and standard errors of means) for the different scalp locations, separately for the four conditions (columns) and the five measurement intervals (rows) in Experiment 2. Note the different amplitude scales in the different rows.

Overview of the statistical test-results for Experiment 1, for each comparison and ERP latency-range. The labels indicate whether a significant interaction involving both Condition and Stimulus factors was found

Table 1

Comparison	N1	N2	P3a	LN1	LN2
Fully Predictable vs. Unpredictable—Single Deviant	ns	**	*	**	***
Unpredictable—Single Deviant vs. Multiple Deviants	ns	ns	ns	ns	*
Fully Predictable—Single Deviant vs. Multiple Deviants	ns	ns	ns	ns	ns
Fully Predictable vs. Predictable Sound Probability vs. Unpredictable—Multiple Deviants	ns	**	*	*	***

ns—no significant effect.
* $p < .05$.
** $p < .01$.
*** $p < .001$.

Table 2

Results of the Condition (Fully Predictable—Single Deviant vs. Multiple Deviants) $\times$ Stimulus $\times$ Electrode ANOVAs of the ERP amplitudes elicited by tones in each measurement interval in Experiment 1. (Only significant effects are reported.)

P3a	Electrode	$F(4,64) = 6.89, \varepsilon = .61, \eta_p^2 = .30, p < .01$
	Stimulus $\times$ Electrode	$F(4,64) = 4.63, \varepsilon = .59, \eta_p^2 = .22, p < .05$
LN 1	Stimulus	$F(1,16) = 9.55, \eta_p^2 = .32, p < .01$
	Electrode	$F(4,64) = 26.96, \varepsilon = .73, \eta_p^2 = .63, p < .001$
	Stimulus $\times$ Electrode	$F(4,64) = 5.17, \varepsilon = .55, \eta_p^2 = .24, p < .01$
LN 2	Electrode	$F(4,64) = 13.28, \varepsilon = .47, \eta_p^2 = .45, p < .001$
	Stimulus $\times$ Electrode	$F(4,64) = 10.30, \varepsilon = .56, \eta_p^2 = .39, p < .001$

Table 3

Results of the Condition (Fully Predictable vs. Predictable Sound Probability vs. Unpredictable—Multiple Deviants) $\times$ Stimulus $\times$ Electrode ANOVAs of the ERP amplitudes elicited by tones in each measurement interval in Experiment 1. (Only significant effects are reported.)

P3a	Condition	$F(2,32) = 5.09, \varepsilon = .89, \eta_p^2 = .39, p < .05$
	Stimulus	$F(1,16) = 8.06, \eta_p^2 = .33, p < .05$
	Electrode	$F(4,64) = 5.94, \varepsilon = .63, \eta_p^2 = .27, p < .001$
	Condition $\times$ Stimulus	$F(2,32) = 4.07, \varepsilon = .72, \eta_p^2 = .20, p < .05$
	Stimulus $\times$ Electrode	$F(4,64) = 19.29, \varepsilon = .66, \eta_p^2 = .55, p < .001$
LN1	Stimulus	$F(1,16) = 5.00, \eta_p^2 = .24, p < .05$
	Electrode	$F(4,64) = 30.87, \varepsilon = .70, \eta_p^2 = .66, p < .001$
	Condition $\times$ Stimulus	$F(2,32) = 3.55, \varepsilon = .90, \eta_p^2 = .18, p < .05$
	Stimulus $\times$ Electrode	$F(4,64) = 3.98, \varepsilon = .61, \eta_p^2 = .20, p < .05$
LN2	Stimulus	$F(1,16) = 4.81, \eta_p^2 = .23, p < .05$
	Electrode	$F(4,64) = 15.12, \varepsilon = .53, \eta_p^2 = .46, p < .001$
	Condition $\times$ Electrode	$F(8,128) = 4.27, \varepsilon = .47, \eta_p^2 = .21, p < .01$
	Condition $\times$ Stimulus $\times$ Electrode	$F(8,128) = 8.28, \varepsilon = .44, \eta_p^2 = .34, p < .001$

Table 4

Overview of the statistical test-results for Experiment 2, for each comparison and ERP latency-range. The labels indicate whether a significant interaction involving both Condition and Stimulus factors was found

Comparison	N1	N2	Early P3a	late P3a	LN1	LN2
Fully Predictable vs. Unpredictable—Single Deviant	***	***	**	***	***	***
Unpredictable—Single Deviant vs. Multiple Deviants	**	*	ns	ns	**	ns
Fully Predictable—Single Deviant vs. Predictable Sound Probability – Multiple Deviants	***	ns	***	***	*	***
Predictable Sound Probability vs. Unpredictable – Multiple Deviants	***	***	**	***	**	**

ns—no significant effect.
* $p < .05$.
** $p < .01$.
*** $p < .001$.

Table 5

Results of the Condition (Fully Predictable—Single Deviant vs. Predictable Sound Probability—Multiple Deviants) $\times$ Stimulus $\times$ Electrode ANOVAs of the ERP amplitudes elicited by tones in each measurement interval in Experiment 2. (Only significant effects are reported.)

Early P3a	Condition	$F(1,15) = 7.00, \eta_p^2 = .32, p < .05$
	Electrode	$F(4,60) = 9.53, \varepsilon = .46, \eta_p^2 = .39, p < .001$
	Condition $\times$ Stimulus	$F(1,15) = 7.38, \eta_p^2 = .33, p < .05$
	Condition $\times$ Electrode	$F(4,60) = 19.47, \varepsilon = .58, \eta_p^2 = .56, p < .001$
	Stimulus $\times$ Electrode	$F(4,60) = 26.11, \varepsilon = .53, \eta_p^2 = .64, p < .001$
	Condition $\times$ Stimulus $\times$ Electrode	$F(4,60) = 12.43, \varepsilon = .49, \eta_p^2 = .45, p < .001$
Late P3a	Condition	$F(1,15) = 15.95, \eta_p^2 = .52, p < .01$
	Electrode	$F(4,60) = 14.74, \varepsilon = .51, \eta_p^2 = .50, p < .001$
	Condition $\times$ Stimulus	$F(1,15) = 17.93, \eta_p^2 = .54, p < .001$
	Condition $\times$ Electrode	$F(4,60) = 32.72, \varepsilon = .68, \eta_p^2 = .69, p < .001$
	Stimulus $\times$ Electrode	$F(4,60) = 32.49, \varepsilon = .46, \eta_p^2 = .68, p < .001$
	Condition $\times$ Stimulus $\times$ Electrode	$F(4,60) = 21.71, \varepsilon = .54, \eta_p^2 = .59, p < .001$
LN 1	Stimulus	$F(1,15) = 17.29, \eta_p^2 = .54, p < .001$
	Electrode	$F(4,60) = 9.22, \varepsilon = .44, \eta_p^2 = .38, p < .01$
	Condition $\times$ Stimulus	$F(1,15) = 5.59, \eta_p^2 = .27, p < .05$
LN 2	Stimulus	$F(1,15) = 26.53, \eta_p^2 = .64, p < .001$
	Electrode	$F(4,60) = 6.95, \varepsilon = .43, \eta_p^2 = .32, p < .01$
	Condition $\times$ Electrode	$F(4,60) = 5.76, \varepsilon = .61, \eta_p^2 = .28, p < .01$
	Condition $\times$ Stimulus $\times$ Electrode	$F(4,60) = 10.34, \varepsilon = .59, \eta_p^2 = .41, p < .001$

Table 6

Results of the Condition (Predictable Sound Probability vs. Unpredictable—Multiple Deviants) $\times$ Stimulus $\times$ Electrode ANOVAs of the ERP amplitudes elicited by tones in each measurement interval in Experiment 2. (Only significant effects are reported.)

Early P3a	Stimulus	$F(1,15) = 7.74, \eta_p^2 = .34, p < .05$
	Electrode	$F(4,60) = 11.66, \varepsilon = .49, \eta_p^2 = .44, p < .001$
	Condition $\times$ Electrode	$F(4,60) = 3.78, \varepsilon = .58, \eta_p^2 = .20, p < .05$
	Stimulus $\times$ Electrode	$F(4,60) = 37.86, \varepsilon = .53, \eta_p^2 = .72, p < .001$
	Condition $\times$ Stimulus $\times$ Electrode	$F(4,60) = 6.12, \varepsilon = .68, \eta_p^2 = .29, p < .01$
Late P3a	Stimulus	$F(1,15) = 30.61, \eta_p^2 = .67, p < .001$
	Electrode	$F(4,60) = 6.79, \varepsilon = .50, \eta_p^2 = .31, p < .01$
	Condition $\times$ Stimulus	$F(1,15) = 19.27, \eta_p^2 = .56, p < .001$
	Condition $\times$ Electrode	$F(4,60) = 17.40, \varepsilon = .65, \eta_p^2 = .54, p < .001$
	Stimulus $\times$ Electrode	$F(4,60) = 53.46, \varepsilon = .54, \eta_p^2 = .78, p < .001$
	Condition $\times$ Stimulus $\times$ Electrode	$F(4,60) = 8.35, \varepsilon = .57, \eta_p^2 = .36, p < .001$
LN 1	Condition	$F(1,15) = 4.74, \eta_p^2 = .24, p < .05$
	Electrode	$F(4,60) = 9.87, \varepsilon = .53, \eta_p^2 = .40, p < .001$
	Condition $\times$ Stimulus	$F(1,15) = 14.66, \eta_p^2 = .49, p < .01$
	Condition $\times$ Electrode	$F(4,60) = 4.69, \varepsilon = .51, \eta_p^2 = .24, p < .05$
LN 2	Stimulus	$F(1,15) = 26.06, \eta_p^2 = .63, p < .001$
	Electrode	$F(4,60) = 6.71, \varepsilon = .44, \eta_p^2 = .31, p < .01$
	Condition $\times$ Electrode	$F(4,60) = 8.49, \varepsilon = .65, \eta_p^2 = .36, p < .001$
	Stimulus $\times$ Electrode	$F(4,60) = 5.34, \varepsilon = .42, \eta_p^2 = .26, p < .05$
	Condition $\times$ Stimulus $\times$ Electrode	$F(4,60) = 6.63, \varepsilon = .62, \eta_p^2 = .31, p < .01$