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Preventing distraction by probabilistic cueing

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ABSTRACT

Involuntary attention switches triggered by infrequent, unpredictably occurring sensory events (distraction) can be prevented when participants are made aware of the forthcoming distractor. Previous studies exploring this phenomenon presented visual cues before each stimulus in an auditory oddball sequence. In one condition, cues were completely reliable in predicting the forthcoming distractor or standard sound, in another, separate condition, they were completely unreliable. These studies found that in the condition with reliable cues, distraction was reduced compared to that with unreliable cues, as signaled by decreased reaction time delay as well as reduced P3a and reorienting negativity event-related potentials. Whereas these results are generally interpreted as the results of preparatory processes initiated by the cues, it could be argued that the preventive effect is a byproduct of increased information processing load in the condition with informative cues compared to that in the condition with uninformative ones. In the present study, using 80% reliable visual cues preceding tones in an oddball sequence, it was demonstrated that distraction can be prevented when the trials with valid and invalid cues were presented within a single experimental condition, as shown by reduced reaction time delay and P3a amplitude. These results are compatible with the notion that the distraction is prevented by means of preparatory processes initiated by the cues.

1. Introduction

Many tasks in everyday life demand the maintenance of a selective attention set: to perform efficiently, we have to monitor task-relevant sources of information while disregarding others. Our efforts, however, are often unsuccessful: unpredictably occurring, rare sensory events capture our attention despite being task-irrelevant; in other words, we get *distracted*. Under normal circumstances, processes leading to distraction and those supporting the maintenance of a focused attention set are well-balanced: we can perform the task at hand without many interruptions, but occasional episodes of distraction allow us to re-evaluate our goals and priorities (e.g. the distraction caused by the fire-alarm allows us to change our behavior adaptively). Recent studies show that this balance can be dynamically adjusted, that is, we can prevent or counteract distraction when we are made aware of forthcoming, potentially distracting events. A cue preceding such an event allows one to reduce distraction as measured by behavioral and event-related potential (ERP) indices (Sussman et al., 2003; Wetzel and Schröger, 2007; Wetzel et al., 2009; Horváth et al., 2011). The goal of the present study was to investigate the mechanism behind this cueing effect.

Distraction-related processing is usually investigated in studies presenting *oddball* stimulus sequences to participants. In such sequences, most stimuli (termed *standards*) conform to a regularity, which is occasionally violated by unpredictably occurring stimuli (*deviants*). A paradigm using such an oddball sequence introduced by Schröger and Wolff (1998a) proved to be highly useful for investigating distraction. In the prototypical paradigm, a sequence of short and long tones is presented with 50–50% probability, and participants perform a two-alternative forced choice duration discrimination task. Occasionally (typically with 5–20% probability), a task-irrelevant feature of the given tone (e.g. its frequency) is changed (deviants). Because participants perform the same duration discrimination task for deviants as for standards, it is assumed that differential responses to deviants and standards reflect processes solely related to distraction. For deviants, reaction times are typically delayed, error rates may increase, and a characteristic sequence of ERPs can be observed (Escera and Corral, 2007): deviants elicit an enhanced N1 (around 100 ms post stimulus onset; Näätänen and Picton, 1987) and the mismatch negativity (MMN, peaking between 100 and 250 ms post deviance onset; see Näätänen et al., 1978; for recent summaries see Kujala et al., 2007; Winkler, 2007). These are followed by the P3a or novelty-P3 (peaking around 300 ms after deviance onset; Friedman et al., 2001; Polich, 2007), which is usually interpreted as the correlate of attention switching (Escera et al., 2000; but see Horváth et al., 2008). Finally, because the deviant information is irrelevant for the participant in this experimental setting, the task-optimal attention set has to be restored, which is assumed to be reflected by the

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reorienting negativity (RON, peaking between 400 and 600 ms after deviance onset; Schröger and Wolff, 1998b).

Sussman et al. (2003) modified the auditory distraction paradigm summarized above by presenting visual cues before each tone. In one condition, the cues were informative regarding the task-irrelevant dimension of the forthcoming tone (i.e. its frequency), in the other they were not. Informative cues allowed participants to reduce the effects of distraction, as signaled by decreased reaction time delay as well as reduced P3a and RON amplitudes compared to the condition with uninformative cues (see also Wetzel and Schröger, 2007; Wetzel et al., 2009; Horváth et al., 2011). This result was interpreted as the reflection of preparatory activity for the forthcoming distractor.

In the following, we offer an alternative explanation for these results, which is based on the fact that the studies cited above manipulated cue reliability in separate conditions. In one condition, the cue was completely reliable, that is, the correlation between the appearance of the cue and the distractor was 100%; in the other condition, the cue was completely unreliable, that is, the correlation was 0. Since participants knew about the reliability of the cues within each experimental block, one could argue that in each condition (and each block) participants adopted different strategies for processing the cues: When the cue was completely unreliable, participants probably refrained from making an effort to "figure out" the meaning of the cue, whereas they were engaged in processing the meaning of the cue when the cues were reliable. These hypothetical cue-evaluation strategies would result in different information processing loads, which may lead to the observed distraction-preventive effects: Distractors may be less efficient when cues are completely reliable because information processing resources are engaged by cue processing. That is, the distraction-preventive effect may not be due to direct preparatory activities, but rather, it may be an indirect (but useful) byproduct of a difference in information processing load. That a higher information processing load may result in lower distractibility as indexed by the P3a and RON amplitudes has been shown in the context of the prototypical distraction paradigm by Berti and Schröger (2003). That information load may be different between the two conditions is supported by previous studies: in the study by Wetzel and Schröger (2007) infrequent visual cues did not elicit a P3b at all in the uninformative condition. Similarly, in the Sussman et al. (2003) and Horváth et al. (2011) studies, P3b amplitudes elicited by infrequent visual cues were higher when cues were informative than when they were not. Since the P3b amplitude correlates with the task-relevancy of a stimulus (see e.g. Donchin et al., 1978), these results indicate that obviously uninformative cues may simply be disregarded by the participants.

The goal of the present study was to investigate whether distraction could be prevented by cueing when the adoption of different cue-processing strategies was not feasible. To this end, we used a single setting with 80% reliable cues instead of two experimental conditions with completely reliable in one and unreliable cues in the other. Using such probabilistic cues has proven to be a robust experimental manipulation of the allocation of attention (see, e.g. Posner, 1980; Mondor and Bregman, 1994), therefore, it seems to be safe to assume that cues with 80% reliability would still encourage participants to utilize this information, and it would allow the presentation of standard and potentially distracting events preceded by valid and invalid cues within the same experimental setting.

2. Methods

2.1. Participants

Twelve paid young adult volunteers (seven women, aged 18–24 years, mean age: 22 years; all right-handed) reporting normal hearing status and normal or corrected-to-normal vision participated in the experiment. They received modest financial compensation and gave written informed consent after the experimental procedures were explained to them. This research has been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki.

2.2. Stimuli and procedure

The experimental procedures and stimulation closely follow that in Sussman et al. (2003) and Horváth et al. (2011). Participants were seated in a comfortable chair in a well-lit, sound-attenuated room during the experiment. In each experimental block, a sequence of sinusoid tones was presented through headphones (HD-600, Sennheiser, Wedemark, Germany) with an onset-to-onset interval of 1200 ms. The intensity of the tones was individually adjusted to 50 dB sensation level (above hearing threshold level). The duration of the tones was 100 or 200 ms (including 5–5 ms linear rise and fall times) and their frequency was 988 (low) or 1397 Hz (high). Trials were presented in random order: trials with short and long tone durations were presented with equal (50–50%) probability; the tone probabilities were, on the other hand, asymmetric: trials with one of the frequencies were presented with 13.3% (*deviant* trials), the other with 86.7% probability (*standard* trials). The deviant-standard role was reversed in half of the blocks, and the two types of blocks (i.e. those with high deviants, and those with low deviants, denoted with A and B in the following) were presented in an interwoven order ("ABBAABBA…" for half of the participants and "BAABBAAB…" for the other half). Tone duration and tone frequency were independently varied.

The participants' task was to press a button held in their (dominant) right hand when they heard a long (200 ms) tone, but withhold the response if the tone was short (100 ms), irrespective of the tone frequency. The instruction emphasized that responses should be fast, but correct. The participants were instructed to look at a $0.45 \times 0.45°$ (height × width) fixation cross presented in gray (33 cd/m^2) on a black (2 cd/m^2) background in the middle of the screen 125 cm in front of them. Before each tone, a visual cue was presented. Cues were $1.23 \times 1.23°$ gray (33 cd/m^2) squares. The gray squares were presented 1.83° above (high cue) or below (low cue) the fixation cross (measured from the middle of the square to the middle of the cross). Cues were presented for 100 ms. 346 ms after the onset of the visual cue, a sound was presented. On 80% of the trials, a high tone was preceded by a high cue, or a low tone was preceded by a low cue. On the remaining 20% of the trials, high or low tones were preceded by an invalid cue announcing the other frequency. Though cues were not informative regarding tone duration, participants were instructed to attend the cues, because "they may still help to better prepare for the forthcoming tone". Participants were also informed about the 80% reliability of the cues.

Each experimental block started with a "reminder sequence": a sequence of six trials which were correctly cued. The first two of these were always a short and a long standard trial to remind participants of the relevant duration difference, and the third and sixth trials were always deviants. The next 150 trials were a random sequence of 52–52 correctly cued long and short standard, 13–13 incorrectly cued long and short standard, 8–8 correctly cued long and short deviant, and 2–2 incorrectly cued long and short deviant trials. With 156 trials, each block was about 3 min long. There were 20 experimental blocks overall, which were separated by short breaks (1–2 min) as needed. After each block, feedback about the behavioral performance was given (correct response rate, average reaction time, and the distribution of all correct response times within the block — this was used to emphasize and check compliance with the speed instruction). A longer (5–10 min) break was inserted after the tenth block.

Before administering the experiment as described above, participants were familiarized with the stimulation and the task. First they practiced the task with one or two random tone sequences composed