



Knowledge of sequence structure prevents auditory distraction: An ERP study



Márta Volosin^{*}, János Horváth

Institute of Cognitive Neuroscience and Psychology, Research Centre for Natural Sciences, Hungarian Academy of Sciences, Budapest, Hungary

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ABSTRACT

Infrequent, salient stimuli often capture attention despite their task-irrelevance, and disrupt on-going goal-directed behavior. A number of studies show that presenting cues signaling forthcoming deviants reduces distraction, which may be a “by-product” of cue-processing interference or the result of direct preparatory processes for the forthcoming distracter. In the present study, instead of “bursts” of cue information, information on the temporal structure of the stimulus sequence was provided. Young adults performed a spatial discrimination task where complex tones moving left or right were presented. In the predictable condition, every 7th tone was a pitch-deviant, while in the random condition the position of deviants was random with a probability of 1/7. Whereas the early event-related potential correlates of deviance-processing (N1 and MMN) were unaffected by predictability, P3a amplitude was significantly reduced in the predictable condition, indicating that prevention of distraction was based on the knowledge about the temporal structure of the stimulus sequence.

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1. Introduction

Many tasks in our everyday life require the filtering of task-relevant and task irrelevant sensory events: Task-relevant events have to be processed as fast as possible, while task-irrelevant events should not consume processing resources at all. Such a “perfect” selective attention set, however, cannot be established: Unpredictable, rare stimuli easily capture our attention and disrupt the ongoing task-related behavior, that is, we get *distracted*. A number of studies show that the sensory system automatically responds to unpredictable, rare stimulus events (for a summary, see Escera et al., 2000), which may lead to involuntary allocation of attention to such events (Schröger, 1997). Recent studies show that when forthcoming, potentially distracting events are preceded by informative cues, the effects of distraction are reduced or eliminated (Sussman et al., 2003; Horváth et al., 2011; Horváth and Bendixen, 2012; Wetzel and Schröger, 2007; Wetzel et al., 2009, 2012). The goal of the present study was to investigate whether the prevention of distraction was also possible by providing information on forthcoming distracters without relying on explicit cues.

Cognitive processing related to distraction is usually investigated in oddball-paradigms, in which the presentation of frequent *standard* stimuli is interrupted by infrequent *deviants*. A variant of the oddball paradigm developed by Schröger and Wolff (1998b) allows unique

insights into distraction-related processing. In this paradigm, long and short tones are presented equiprobably, and participants perform a duration discrimination task. Occasionally, randomly, the task-irrelevant tone pitch is changed (in about 10% of the trials). For such deviants, prolonged response times, reduced hit rates and more false alarms were found than for standards. Distraction effects can be found at the electrophysiological level as well: After deviance onset, a characteristic waveform can be observed in the deviant-minus-standard event-related potential (ERP) difference, starting with an enhanced N1 and mismatch negativity (MMN) at 100–250 ms, followed by a positivity at around 300 ms (P3a), and finally a negative deflection occurs peaking around 500 ms (reorienting negativity – RON). The N1-effect and MMN reflect the activity of sensory change detection processes (Näätänen, 1982). P3a is generally assumed to reflect involuntary attention switching (Friedman et al., 2001; Polich, 2007), while RON is theorized to reflect the reorientation of attention to the original task (Schröger and Wolff, 1998a; Sussman et al., 2003). Similar results were found in auditory-visual paradigms in which targets were visual stimuli (e. g. odd or even numbers) and the distractors were sounds (Escera et al., 1998, 2000, 2001). Although the early studies using either auditory (Berti and Schröger, 2003; Schröger and Wolff, 1998a,b) or auditory-visual (Escera et al., 1998, 2000, 2001) paradigms consistently found prolonged response times (RTs) and decreased accuracy, recent studies found abolished or even reversed behavioral effects (Li et al., 2013; Parmentier et al., 2010; SanMiguel et al., 2010a,b; Wetzel et al., 2012). These studies suggest that alerting and fore-period effects differ between standards and deviants, and these differences influence the behavioral results.

^{*} Corresponding author at: Institute of Cognitive Neuroscience and Psychology, RCNS, HAS, P. O. Box: 286, Budapest 1519, Hungary. Tel.: +36 1 382 6819.

E-mail addresses: volosin.marta@ttk.mta.hu (M. Volosin), horvath.janos@ttk.mta.hu (J. Horváth).

Interestingly, the paradigm can be also utilized to assess whether distraction can be prevented or reduced. *Sussman et al. (2003)* utilized the paradigm developed by *Schröger and Wolff (1998b)* but they presented visual cues before each tone. In the predictable condition, cues indicated whether the forthcoming tone was a standard or a pitch-deviant. In the unpredictable condition, the cues did not allow predicting whether the forthcoming tone was a standard or a deviant. In the unpredictable condition, the expected distraction effects were found: (delayed RTs to deviants in comparison to standards, and the elicitation of N1/MMN, P3a, and RON). In the predictable condition, however, the RT-delay, P3a and RON were abolished (predictability had no effect on the N1/MMN). These results were replicated in several studies using different experimental designs and manipulations of presentation (*Horváth et al., 2011; Horváth and Bendixen, 2012; Wetzel and Schröger, 2007; Wetzel et al., 2009*).

These studies showed that cues providing different degrees of predictability allow the reduction of distraction, but the mechanism behind the cuing effect is not fully understood yet. Although the prevalent interpretation of the cuing effect is that cues allow one to prepare for, and prevent distraction caused by deviants (“preparation”-hypothesis), other interpretations are also possible. The main alternative interpretation is that distraction-prevention is a “byproduct” of cue-processing: Because cues deliver information commensurate to that of the forthcoming deviant (i.e. their presentation frequencies are necessary the same, therefore deviant cues are deviants themselves within the cue sequence), processing this sudden “burst” of information may temporarily deplete processing resources, which in turn, may lead to reduced distraction effects. Direct evidence against the “byproduct”-hypothesis is scarce. There is only one study, conducted by *Parmentier and Hebrero (2013)*, which showed that cues allowing the prediction of forthcoming deviants reduced distraction-related response-time delays even if the cues preceded the deviants by as much as 2250 ms (i.e. the reduction of RT-delay did not differ from that at 250 ms cue-tone separation). Because it seems unlikely that cue-related processing would block further processing for such a long time, this result supports the “preparation” account of the cuing effect.

The goal of the present study was to investigate distraction-prevention using the method of ERPs in a setting in which information on forthcoming distracters was not delivered in “bursts”, but was available continuously. Investigating whether distraction can be reduced in this setting is important, because such an arrangement would allow the comparison of distraction-prevention ability between groups potentially differing in their ability to process and utilize “bursts” of information. That is, the continuous availability of cue-information would eliminate confounds due to potential between-group cue-processing abilities. For example, if processing “burst”-like cues required 300 ms on average in one group, but required 500 ms in another, then cues appearing 400 ms before distracters would allow one group to fully prepare for the forthcoming distracters, while leaving the other groups prone to their distracting effects. In this example, one would measure between-group differences in the efficiency in distraction-prevention, but these differences would not reflect the ability to prevent distraction, rather, they would reflect a difference in cue information processing speed. Furthermore, even if the cue-distracter separation allowed both groups to process cue information in time, the utilization of this information depends on the willingness of participants to do so. The amount of effort needed to process cue information in the short time available may reduce the participants' motivation to utilize cue information at all (*Horváth, 2013*).

We administered an auditory distraction paradigm in which the presentation order of tones was either predictable (every 7th tone was pitch-deviant) or random (with 1:6 deviant:standard ratio). The tones virtually moved either to the left or to the right and participants responded to the direction of the movement, ignoring sound frequency. As in previous studies, deviants in the predictable condition should be less distracting than those in the random condition because of the

availability of information on forthcoming deviants. This arrangement, however, still provides a challenge: participants have to keep the current position within the sequence in mind to be able to prepare for forthcoming deviants. In order to minimize the effort needed, a visual counter showing the sequence position was presented as a constant reminder, which made information on forthcoming tones continuously available throughout the experimental blocks of the predictable condition. We hypothesized that knowledge about the stimulus sequence would reduce or abolish behavioral and ERP effects of distraction.

2. Material and methods

2.1. Participants

14 healthy young volunteers participated in the experiment (9 women, aged: 19–26 years, mean age: 22 years). All participants reported normal hearing and normal or corrected-to-normal vision. They received either modest financial compensation or course credit for participation, and gave written informed consent before the experiment, after the experimental procedures were explained to them.

2.2. Materials and procedure

Participants were sitting in a comfortable chair in a sound-attenuated room during the experiment. Each experimental block consisted of either random or predictable sequences of complex spatial sounds with 1300 ms SOA, through a Sennheiser (HD-600, Sennheiser, Wedemark, Germany) headphone. The intensity of sounds was individually calibrated to 50 dB sensation level above the hearing threshold, determined by the method of limits.

Tones were generated with Csound version 5.7.11, using the head related transfer function tool “hrtfmove2” to simulate virtual movement. Due to a programming error, tones were generated with 44.1 kHz sampling frequency, but replayed with 48.0 kHz, which did not substantially alter the perceived virtual movement. The frequency and velocity data values reported below correspond to what participants actually heard.

The duration of each tone was 643 ms, with 9 ms rise and fall times. Each tone started on the virtual midline (they could be heard in both ears equally), then after 184 ms they moved 20° toward the left or right (50–50% probability) with constant angular velocity in 459 ms, i.e. angular velocity was 43.54°/s. The tones were complex tones with six harmonics. The fundamental frequency of the tones was either 254 Hz (high) or 202 Hz (low). The amplitudes of the five harmonic overtones were 80%, 40%, 50%, 30% and 90% of the amplitude of the fundamental. Both frequencies could function as deviant (14.28%) or standard (85.71%). The role of frequencies (standard or deviant) was counterbalanced between participants: For seven participants, standards were high, and for the other seven standards were low.

The participants' task was to indicate whether the tone moved to the left or to the right (regardless of its frequency), by pressing the key held in their corresponding hand. The instruction was to respond as fast and accurately as possible, immediately when the direction of the virtual movement could be assessed (without waiting for the sound-offset). Participants were informed before each block whether the presentation of the block was predictable or random. Each block consisted of frequent standard and rare deviant stimuli, presented with a 6:1 ratio. Thus, 154 tones were presented in each block (132 standards and 22 deviants). In predictable blocks every 7th tone was deviant, in random blocks the tone order was randomized while keeping the 6:1 standard:deviant ratio.

To support keeping the current sequence position (and the forthcoming deviant tone) in mind, a visual counter was presented on a screen. Black digits from 1 to 7 were presented continuously in linear order in the middle of the gray screen, under a viewing angle of about 7°. The transition between digits occurred 44 ms before each tone. In

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