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Context effects on auditory distraction

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ABSTRACT

The purpose of the study was to test the hypothesis that sound context modulates the magnitude of auditory distraction, indexed by behavioral and electrophysiological measures. Participants were asked to identify tone duration, while irrelevant changes occurred in tone frequency, tone intensity, and harmonic structure. Frequency deviants were randomly intermixed with standards (Uni-Condition), with intensity deviants (Bi-Condition), and with both intensity and complex deviants (Tri-Condition). Only in the Tri-Condition did the auditory distraction effect reflect the magnitude difference among the frequency and intensity deviants. The mixture of the different types of deviants in the Tri-Condition modulated the perceived level of distraction, demonstrating that the sound context can modulate the effect of deviance level on processing irrelevant acoustic changes in the environment. These findings thus indicate that perceptual contrast plays a role in change detection processes that leads to auditory distraction.

1. Introduction

A couple talking next to you while reading a book and sipping coffee at your local Starbucks will likely be perceived as less distracting than a couple talking next to you at the same level of loudness while reading at your local library. That is, the perceived degree of distraction will be influenced by the context of the ambient noise. The goal of the current study was to test the hypothesis that contextual factors of the overall sound environment modulate auditory distraction effects.

Previous investigations measuring the degree of auditory distraction have focused on the magnitude of a distracting stimulus (Berti, Roeber, & Schröger, 2004; Doeller et al., 2003; Gomes et al., 2000; Rinne et al., 2007; Tse & Penney, 2008; Wetzel, Widmann & Schröger, 2006). In general, these studies have shown a positive relationship between an increase in magnitude of the physical sound and an increase in both behavioral and electrophysiological measures of distraction. The purpose of the current study was to determine whether the physical magnitude of a distracting stimulus would be perceptually modulated by the contextual environment, such that the same physical magnitude of a sound may be elicit more or less distraction depending upon the context it occurs, not by the magnitude of the stimulus itself.

When an unexpected sound event occurs, further evaluation is needed to determine its relevancy to current behavior (Friedman, Cycowicz, & Gaeta, 2001; Ruhnau, Wetzel, Widmann, & Schröger, 2010; Sussman, Winkler, & Schröger, 2003; Sussman, 2007). This "further evaluation" causes a measure of distraction due to the momentary reorienting of attention, which has been observed as a longer reaction time in behavioral performance on the target task, and by a lower accuracy for the target tones that also contain the distracting element (Schröger, Giard, & Wolff, 2000). Furthermore, a corresponding neurophysiologic marker of attentional orienting called the P3a component is observed to the irrelevant, distracting event (Friedman et al., 2001). Additionally, the irrelevant sound change elicits the mismatch negativity (MMN) component, prior in time to the P3a component. It is generally thought that the MMN component reflects the sound change detection (Näätänen, 1990), and the P3a component reflects the attention-switching to the change for further evaluation (Friedman et al., 2001).

Schröger and Wolff (1998) also reported a component following the P3a they called the "reorienting negativity" (RON), and defined it as a measure of reorienting back to the main task (Berti et al., 2004; Schröger & Wolff, 1998). From their observations, Berti et al. (2004) suggested a "three-stage model of auditory distraction" linked to this chronological sequence of event-related potentials (ERPs): the change detection (indexed by MMN), orienting to the distracting event (indexed by P3a) and then reorienting back to the main task (indexed by RON). Taken together, Berti et al. suggest that these neurophysiologic measures provide a temporal 'tracking' ultimately reflected in the measures of behavioral distraction. According to this model, the neurophysiologic measures should

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concordantly reflect the amount of distraction induced by a stimulus. And consistency between stimulus magnitude and measures of distraction has been reported in studies investigating distraction via irrelevant frequency changes (Berti et al., 2004; Gomes et al., 2000; Rinne et al., 2007), irrelevant intensity increments (Rinne, Särkkä, Degerman, Schröger, & Alho, 2006), irrelevant location changes (Sonnadara, Alain, & Trainor, 2006), and irrelevant temporal changes (Kisley et al., 2004).

However, temporal tracking indices of distraction have not been found for magnitude of intensity decrements (Rinne et al., 2006). Rinne et al. (2006) reported only an MMN component elicited by intensity decrements, without any P3a. This occurred even though in the same study intensity increments elicited both MMN and P3a components, as well as an N1 enhancement (a larger N1 amplitude to the louder intensity compared to the standard intensity tones). This result led Rinne et al. to conclude that the P3a component indexes attentional orienting only when the N1 mechanism is involved (i.e., only when an N1 enhancement is also observed). Horváth, Czigler, et al. (2008) went one step further, to suggest that the change in MMN amplitude associated with the magnitude of deviance observed in previous studies was actually a confound of the N1 mechanism and not a magnitude effect at all. Horváth et al. reported that after minimizing the contribution of the N1 component, there was no significant change of MMN amplitude with the magnitude of deviance level. These results argue against a 'three-stage model' or a magnitude effect for processing distracting auditory events (Horváth, Winkler, & Bendixen, 2008; Rinne et al., 2006).

In the current study, we explored an alternative hypothesis to these explanations, that is, the sound environment (or context) primarily influences the perceived magnitude of distracting events. From this perspective, the divergence of results found among the studies of Schröger and colleagues may be explained, at least in part, by a change in the sound context. For example, Berti et al. (2004) and Rinne et al. (2006) used a mixed-block design: all of the deviants were mixed together in each run. They then analyzed the magnitude of the responses in comparison with the tones occurring together within the block. In these study designs, the surrounding stimulus environment was the same in all presentation blocks. In contrast, in Horváth, Czigler, et al. (2008) and Horváth, Winkler, et al. (2008), a single-block design was used: each distracting deviant stimulus was presented separately, singly in separate stimulus blocks. Using this design, no magnitude effect was found (after removing the influence of the N1 effect). Thus, our proposed hypothesis would explain these seemingly disparate results in terms of the context difference. The magnitude effect found in Rinne et al. would be due to being able to compare differences in stimulus magnitude for stimuli presented together in the same block, whereas the absence of a magnitude effect in Horváth et al. would be due there being no comparison to be made among the different stimuli because they was only one distracting event in each block. The single-block design of Horváth et al. may have induced a different expectation, or attentional bias, compared to when processing the different deviant stimuli altogether in one block.

Context effects may also explain the seemingly contradictory pattern of results observed for the intensity increment vs. decrement effect of deviants in the Rinne et al. (2006) study. That is, when intensity decrements were mixed together with the intensity increments a comparison was set up that reduced (or modified) the saliency of the decrements. Magnitude effects or the absence of them, in both of these studies may thus be explained by mechanisms of perceptual contrast. The context of the auditory environment allows or precludes an ability to compare stimulus magnitude.

To test the context hypothesis contributing to effects of auditory distraction, we conducted two experiments, one that used a mixed-block design with three levels of frequency deviation, three levels of intensity deviation, and one level of stimulus complexity (Experiment 1), and another that manipulated the levels of comparison (Experiment 2). This design allowed us to test whether distraction effects initiated by increasing levels of frequency and intensity changes would be consistent with a linear increase in the stimulus deviance level, as well as the influence of a qualitatively different and salient tone on the magnitude effect.

2. Experiment 1 (Tri-Condition)

Experiment 1 tested the hypothesis that behavioral and electrophysiological indices of auditory distraction will increase linearly with increasing magnitude of a stimulus.

2.1. Method

2.1.1. Participants

Fifteen right-handed healthy adults were paid for their participation (9 females, $M = 26$ years, $SD = 4.3$). All participants provided written informed consent prior to testing, in accordance with the Declaration of Helsinki and approval from the Internal Review Board of the Albert Einstein College of Medicine, where the study was conducted. All participants passed a hearing screen at 20 dB HL for 500, 1000, 2000, and 4000 Hz in both ears, and reported no history of neurological disorders.

2.1.2. Stimuli and procedure

Table 1 details the experimental conditions and stimulus parameters. Pure tone and complex stimuli were created using Neuroscan STIM software^{TM} (Compumedics, El Paso, TX). The standard pure tone ($p = 0.79$) had a frequency of 1046.5 Hz, and an intensity level of 70 dB SPL (called 'standards'). There were seven different deviants ($p = 0.03$, each). Three pure tones were 'frequency' deviants; three pure tones were 'intensity' deviants; and one complex tone was deviant in spectral quality ('complex' tone). The frequency deviants differed from the standard tone only along the frequency dimension (1108.7 Hz, 1174.7 Hz, and 1244.5 Hz, called F1, F2, and F3, respectively). Intensity deviants differed from the standard only along the intensity dimension (74.2 dB, 78.6 dB, and 83.3 dB, called I1, I2, and I3, respectively). The amount of change from the standard was calculated by a log scale (5.94% for level 1 [small deviance], 12.25% for level 2 [medium deviance], 18.92% for level 3 [large deviance]). Thus, this nomenclature (e.g., F1 or I2) denotes the distance of the deviant from the standard, with "1" indicating the distance closest to the standard, and "3" indicating distance furthest from the standard. The deviant spectral tone had the same fundamental frequency of the standard tones (1046.5 Hz) but with 3 harmonic partials. This complex tone was therefore deviant qualitatively but not in frequency or intensity. All tones were presented bilaterally through insert earphones (E-a-rtone® 3A, Indianapolis, IN) once every 1200 ms (onset-to-onset). Half of all the tones were 100 ms duration and the other half of all the tones were 200 ms duration, regardless of their standard or deviant status.

Participants were seated in a comfortable chair in a sound-attenuated recording booth. Participants were instructed to listen to each tone and press a designated button if it was the shorter tone and a different button if it was the longer tone. The frequency, intensity, and spectral changes were irrelevant to the task. Thus, participants were to identify whether they detected the shorter or longer sound on every trial, including the 'deviant' tones that varied in frequency, intensity, and spectral quality. The session began with a short practice for the tone duration discrimination task, followed by 20 experimental blocks of stimuli. Each experimental block contained 150 tones that yields a total of 2370 standard tones and 90 deviants of each type. The standard and deviants were pseudorandomly mixed in each block, so that there were at least two standard tones between any two deviant stimuli. The experimental session was approximately 2.5 h, which included electrode placement and breaks and a snack.

2.1.3. Electroencephalogram (EEG) recording and data analysis

EEG was recorded using a 32-channel electrode cap placed according to the modified International 10–20 System (Jasper, 1958) from FPz, Fz, Cz, Pz, Oz, FP1, FP2, F7, F8, F3, F4, FC5, FC6, FC1, FC2, T7, T8, C3, C4, CP5, CP6, CP1, CP2, P7, P8, P3, P4, O1, O2, and from the left (LM) and right mastoids (RM). Horizontal eye movements were measured by recording the horizontal electro-oculogram (HEOG) in a bipolar configuration between F7 and F8 electrodes. Vertical electro-oculogram (VEOG) was monitored using the FP1 electrode in a biopolar configuration with an external electrode placed below the left eye. The reference electrode was placed at tip of the nose. Impedance was maintained below 5 kΩ across all sites. The EEG and EOG were digitalized at 500 Hz (0.05–100 Hz) and then filtered offline (1–30 Hz). Epochs with activity exceeding ±75 μV at any recorded channel were excluded from further analysis. ERP epochs that contained incorrect responses were also excluded from further analyses. The remaining epochs were then averaged separately for standards and for each of the deviant types. Difference waveforms were