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Effects of explicit knowledge and predictability on auditory distraction and target performance

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ABSTRACT

This study tested effects of task requirements and knowledge on auditory distraction effects. This was done by comparing the response to a pitch change (an irrelevant, distracting tone feature) that occurred predictably in a tone sequence (every 5th tone) under different task conditions. The same regular sound sequence was presented with task conditions varying in what information the participant was given about the predictability of the pitch change, and when this information was relevant for the task to be performed. In all conditions, participants performed a tone duration judgment task. Behavioral and event-related brain potential (ERP) measures were obtained to measure distraction effects and deviance detection. Predictable deviants produced behavioral distraction effects in all conditions. However, the P3a amplitude evoked by the predictable pitch change was largest when participants were uninformed about the regular structure of the sound sequence, showing an effect of knowledge on involuntary orienting of attention. In contrast, the mismatch negativity (MMN) component was only modulated when the regularity was relevant for the task and not by stimulus predictability itself. P3a and behavioral indices of distraction were not fully concordant. Overall, our results show differential effects of knowledge and predictability on auditory distraction effects indexed by neurophysiological (P3a) and behavioral measures.

1. Introduction

To manage the vast amount of sensory information surrounding us, we focus on what is relevant to our current goals and filter out or ignore irrelevant input. Attention involves the interaction of both volitional (top-down knowledge) and automatic processes (stimulus-driven responses), which can influence task performance via interconnected attention networks (Corbetta and Shulman, 2002; Posner, 1980). Attentive processes modify neural activity to facilitate task goals (Lewis et al., 2009; Sawaki et al., 2012; Sussman et al., 2002). However, little is understood about how the stimulus-driven information is stored and monitored that might minimize or interfere with task goals. We tested the hypothesis that knowledge of the sound input, driven by the stimulus statistics, can influence the degree of distraction from the relevant task. Thus, the current study assessed the influence of sequential regularities (stimulus predictability) on behavioral performance and the degree of distraction from the main task. In our previous study, we found that the neurophysiological and behavioral indices of distraction were abated by the predictable occurrence of an irrelevant, distracting tone feature, made predictable by presentation of a visual cue prior to the distracting tone (Sussman et al., 2003). In the current study we tested whether explicit knowledge about the occurrence of a distracting event, but without explicit cueing, would similarly abate distraction effects. That is, would knowledge about the irrelevance of an upcoming event, its predictability, be enough to abate distracting effects; or was there something specific about temporal cueing (e.g., with visual or other input occurring prior to each target) that primarily influenced the distraction effect observed in previous studies (Horváth, 2013; Horváth and Bendixen, 2012; Horváth et al., 2011; Sussman et al., 2003; Volosin and Horváth, 2014). Thus, a second issue addressed by the current paradigm was whether stimulus regularity of the sound input (predictability) would act as a form of implicit cueing, speeding reaction time to targets, and facilitating behavioral responses.

To address these questions, we merged ideas from two different paradigms, a distraction paradigm (Schröger and Wolff, 1998) and a pattern detection paradigm (Sussman et al., 2002). The modified protocol was designed so that the same physical stimulus input would be presented in three different conditions that varied only in the instructions provided to participants as to how to listen and respond to the stimuli. From the pattern detection paradigm (Sussman et al., 2002), a regularly repeating five-tone sequential pattern of stimuli was presented with two different tone frequencies (MMMMHMMMMH…), where "M"

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denotes a middle frequency tone and "H" denotes a higher frequency tone. Another lower frequency tone (L) occurred rarely and served to disrupt the regularly occurring MMMMH pattern (pattern violation). From the auditory distraction paradigm, randomly, half of all the tones were a shorter duration than the other half of the tones (Schröger and Wolff, 1998). The participants' task was to discriminate sound duration in all conditions, pressing one key for the shorter tones and another key for the longer tones. The change in frequency from the M to the H tone was always irrelevant to the tone duration judgment task and served as a potential distracting element of the sequence.

Reaction time (RT) and hit rate (HR) on the primary (tone duration judgment) task was used to quantify effects of knowledge on behavioral distraction: longer RT and lower HR as evidence of distraction. Event-related brain potentials (ERPs) were recorded to assess neurophysiological effects of distraction induced by conditions of knowledge and task. The two dependent ERP measures used were the mismatch negativity (MMN) and P3a components elicited by the regular H tones. The MMN component is elicited by infrequent violations to detected regularities in the sound input (Näätänen et al., 2001) regardless of the direction of attention. However, because MMN is strongly influenced by sound context (which can be implicitly or explicitly determined), and by task performance (involving explicit knowledge of the sound sequence) (Sussman, 2007; Sussman et al., 2013), its elicitation will index when the "H" tone is detected as a frequency deviant, that is, whether or not it was detected as an element of a repeating five-tone (MMMMH) pattern (Sussman and Gumenyuk, 2005; Sussman et al., 2002). The P3a component reflects involuntary orienting away from a primary task to attention-capturing infrequently occurring deviant events (Friedman et al., 2001). Thus, elicitation of the P3a to the pattern-ending H tone will provide an index of distraction, by indexing involuntary orienting to the task-irrelevant pitch change (Schröger and Wolff, 1998; Sussman et al., 2003). P3a is not elicited by standard repeating regularities in a tone sequence.

Conditions were distinguished by the instruction given to participants about how to listen and respond to the patterned sound sequences. In one condition participants were uninformed about the task (Uninformed condition [*UNINF*]). In accordance with other studies (Jankowiak and Berti, 2007; Sussman et al., 2002), we expected that participants would not notice the regular occurrence of the H tone. Accordingly, we expected that the pitch changes (H tones) would elicit MMN and would reflect the involuntarily capture of attention indexed by elicitation of the P3a component. Behavioral distraction effects seen as longer RT and lower HR were likewise expected (Jankowiak and Berti, 2007). This condition was expected to replicate the findings of an auditory distraction paradigm, with the participant having no explicit knowledge of the regularly repeating H tone, and this regularity being irrelevant to the duration judgment task.

In another condition, participants were told about the patterned structure of tone presentation, so that the regular pitch change could be fully predicted (Informed condition [*INF*]). Thus, knowledge about the irrelevant pitch change was provided in advance, instead of in the form of a cue occurring prior to the tone. This knowledge was in the form of information about the structure of presentation of the sound sequence. If the same type of 'cueing' effect (i.e., knowledge about the relevance of the pitch change given in advance) could be implemented by top-down knowledge, then it should have the same abating effect as the cueing paradigm and hence there should be no behavioral distraction effect and a smaller or abolished P3a component (Berti, 2008; Horváth, 2014; Horváth et al., 2011; Horváth and Bendixen, 2012; Horváth et al., 2008; Sussman et al., 2003; Volosin and Horváth, 2014; Wetzel and Schröger, 2007). Additionally, because the regularity is explicit during the task, we also expected that the MMN component could be abolished because the H tone was part of the regularity in the sequence and was not a pitch change per se (Sussman, 2013; Sussman and Gumenyuk, 2005; Sussman et al., 1998; Sussman et al., 2002). However, the regularity was not relevant for the primary task, which was a duration judgment task.

In another condition, the sequential regularity was central to the task in addition to the duration task, so that we could assess the effects of the regularity by task-relevance and not simply by explicit expectation. Participants were instructed to detect pattern violations along with the task of identifying the duration of the tones (*Informed-Detect Pattern Violation* [*INF-DV*]). Thus, in the INF-DV condition, the pattern was made relevant to the task. The relevancy of the pattern to the task goal predicts that MMN would not be elicited by the H tones because the H tones would be part of the regularity involved in the task. We also expected that the tones that were part of the regularity should not evoke distraction effects because they would be fully predicted as part of the task. Only the unexpected infrequent pattern violations were expected to elicit the MMN and P3a components, and reflect behavioral distraction effects. In this way, elicitation of the MMN, or its absence, would index when the pattern regularity was maintained in memory during task performance, with the absence of MMN indicating that the five-tone pattern regularity was neurophysiologically maintained in memory. Elicitation of the P3a would index effects of distraction (involuntary orienting to an unexpected sound change), and further index whether or not pattern regularity and distraction effects were coupled. If explicit cueing is required to abate distraction effects, then the implicit regularity in the sequence should not be enough to do so, and abatement of the ERP distraction effects should only be observed if the regularity was explicitly used to perform the main task.

2. Experimental procedure

2.1. Participants

Sixteen healthy adults (5 males), 19–35 years of age, $M = 24$ years, with reportedly normal hearing, and no neurological disorders, participated in the experiment. Participants were paid or received course credits for their participation. Data were collected at the University of Leipzig, Leipzig, Germany (seven participants) and the Albert Einstein College of Medicine, New York, USA (nine participants). All gave written informed consent after the details of the experimental procedure were explained to them. Protocol and procedures were in accordance with the Declaration of Helsinki. Two subjects were excluded from analysis: one due to poor behavioral performance (hit rates below chance level), and the other to extensive eye movements. The data of the remaining 14 participants were included in this report.

2.2. Stimuli

Three pure tones (5 ms rise and fall time) with frequencies of 748 Hz ($p = 0.032$), 988 Hz ($p = 0.2$), and 880 Hz ($p = 0.768$) were presented with an intensity of 75 dB SPL at an onset asynchrony of 1100 ms. 50% of all frequency tones had a short duration (100 ms) and 50% of all frequency tones had a long duration (200 ms). The medium (880 Hz) and higher (988 Hz) frequency tones were presented in a fixed order, creating a five-tone repeating pattern (MMMMHMMMMH…, where "M" denotes the middle frequency tone and "H" denotes the highest frequency tone). The lowest (748 Hz) frequency tone (denoted with an "L") was pseudo-randomly presented, in place of M tones in the 2nd, 3rd, or 4th position of the five-tone pattern. Fig. 1 displays a schematic of the experimental paradigm used for all three conditions. For each condition, there were five blocks of 42 sound patterns, yielding a total of 210 sound patterns. The L tone occurred in 32 of the patterns.

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