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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.

Keywords

Distraction; attention; P3a; mismatch negativity (MMN); predictability; explicit; implicit knowledge

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-

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driven responses), which can influence task performance via interconnected attention networks (Corbetta et al., 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 et al., 2011; Horváth & Bendixen, 2012; Horváth, 2013; Sussman et al., 2003; Volosin & 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 & 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” 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 & 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 et al., 2002; Sussman & Gumenyuk, 2005). 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 & 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 & Bendixen, 2012; Horváth et al., 2008; Sussman et al., 2003; Volosin & 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 et al., 1998; Sussman, 2013; Sussman & Gumenyuk, 2005; 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, U.S.A (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. Figure 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.

2.3 Data Recording

Continuous electroencephalogram (EEG) was recorded electrodes using an elastic electrode cap from the 32 scalp locations[1] (International 10–20 system: 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 left and right mastoids, LM and RM, respectively). Electrodes were referenced to the tip of the nose. Eye movements were measured by recording the horizontal electrooculogram (EOG) between F7 and F8 and the vertical EOG between Fp1 and an electrode placed below the left eye using a bipolar montage. Impedances were kept below 5 kΩ in all positions. EEG and EOG was digitized (BrainAmp, BRAIN PRODUCTS, Germany, and Neuroscan Synamps, amplifier, Compumedics Corp., Indiana,USA) with a bandpass of .05–100 Hz and a sampling rate of 500 Hz.

2.4 Procedure

Participants were seated in a sound-dampened, electrically-shielded booth (at both sites) and presented with sounds binaurally through Eartone® 3A insert earphones (Aearo Co., Indianapolis, IN). For all conditions, a keypad was used to identify the duration (short or long) of each tone by pressing one of two designated keys with their right and left thumbs. Response-key assignment was counterbalanced across participants. The three conditions differed only in the instructions given to participants about how to listen to and respond to the sounds, thereby altering the knowledge base but not the physical input for each condition. A within-subjects design was used to assess effects of knowledge on distraction. The three conditions were presented in a fixed order: *Uninformed* (UNINF), *Informed* (INF), and *Informed- Detect Pattern Violation* (INF-DV). This was done so that all participants started with no explicit knowledge of the patterned sequence.

In the UNINF condition, participants were not told (were "uniformed") about the regularity of the frequency structure in the tone sequences. They were told to listen to sounds, and for each tone, press one key for the short tone and the other key for the long tone, and to ignore anything else (e.g., pitch changes). In the INF condition, participants were told (were "informed") about the patterned structure of the sound sequence (MMMMH…), so they would know to expect that every fifth tone would be higher-pitched. The purpose for having knowledge about the regularity was to anticipate the regular pitch changes to better ignore it and focus on judging tone duration (the main task of pressing the response key to indicate whether it was the long or short tone on every trial). In the INF-DV condition, participants were again informed about the patterned tone sequence. In addition to pressing one key for short and the other for the long tones, participants were also told that there were infrequent and randomly occurring sound pattern deviants (DV). To designate detection of the pattern deviants, participants were instructed to ***withhold*** their response (i.e., make no duration judgment response) every time they detected a pattern violation. Thus, the L tone served as the "no-go" target. Participants' practiced short tone sequences prior to the EEG recording of each condition to familiarize them with the task. Each session was 135 minutes, including electrode placement time, practice time, recording time, and short breaks.

2.5 Data analysis

2.5.1 Behavioral analysis—Mean HR and mean RT were calculated for each participant, for each stimulus type in each condition, separately. Responses were considered correct if the trigger from the designated key for the short tone or the designated key for the long tone

[1]All of the recording parameters were matched between the two laboratories. One difference was that Ag/AgCI electrodes were used at the German site and tin electrodes at the NY site, however both in placement of 32 channel caps.

were recorded between 250–1000 ms from stimulus onset. False alarms were counted when the designated short key was pressed to a long tone and vice versa (recorded within the 250–1000 ms interval from stimulus onset). Failure to respond was counted as a missed response. Correct rejections were counted in the INF-DV condition as the absence of a response ('no-go' for the duration judgment task) to the L tones. A button press to the L tones in the INF-DV condition was counted as a false alarm. To assess HR, a two-way repeated measures analysis of variance (ANOVA) with factors of condition (UNINF, INF, INF-DV) and stimulus type (L, M, H) was calculated. To assess RT, the two tones of the standard pattern (M, H) were compared across all three conditions (UNINF, INF, INF-DV) using a two-way repeated measures ANOVA. A second two-way repeated measures ANOVA was calculated to compare RT to all three stimulus types (H,M,L) in the two conditions that a button press was made to all tones (UNINF, INF). The correct response to the L-tone in the INF-DV condition was a 'no-go response.

Behavioral distraction effects were delineated by subtracting the average response to the frequent M-tone from the average response to the infrequent pitch changes (H-tone minus M-tone, and L-tone minus M-tone) for both HR and RT, separately in each condition. Condition effects (UNINF, INF, INF-DV) were calculated using a one-way repeated measures ANOVA when all three conditions were compared and students *t*-test for dependent samples when two conditions were compared.

2.5.2 ERP analysis—EEG was filtered off-line with a 0.5–25 Hz bandpass filter with a finite impulse response (FIR) filter (1813-point Kaiser windowed sinc FIR filter; Kaiser beta=5.653, max passband deviation=.001, transition band width=1 Hz) and were divided into epochs of 600 ms time-locked to stimulus onset, including a prestimulus baseline of 100 ms. Any trials showing signal change greater than 75 μV in any recording channel were rejected from averaging (average percentage of rejections was 12%).

The evoked response to the M tones in positions two, three, and four of the five-tone patterns were averaged together to form the 'standard' ERP. The response to the H tone (the fifth tone of the repeating pattern) was averaged separately, and called the 'deviant' ERP. The ERP responses to the M tones that followed the H tone (the first position of the five-tone pattern) were excluded from analysis. The first two patterns of each block were also excluded to eliminate a possible orienting response that may have occurred when starting the sound presentation. Long and short tone trials were collapsed in ERP averaging to increase signal-to-noise ratio (Schröger et al., 2000).

The main comparison to test effects of top-down knowledge on auditory distraction was the response to the H tones compared to the M tones. This was the key comparison across all three conditions because knowledge could modulate the distraction response to the H tone if it were detected as occurring predictably amongst the M tones. That is, distraction effects have been shown to be abated when a change stimulus occurs with foreknowledge (e.g., Sussman et al., 2003). The P3a component indexes orienting to the change stimulus and provides a neurophysiologic measure of distraction (Schröger & Wolff, 1998). To assess neurophysiological effects of distraction in the current study, difference waveforms were calculated by subtracting ERPs elicited by the M tone from the ERPs elicited by the H tone.

ERP components were then visually identified in the respective grand-averaged difference waveforms separately in each condition. Visual identification of the peak latency of the components of interest (MMN and P3a) was made and measurement intervals were chosen centered on the peak latency from the electrode with highest signal-to-noise ratio for each component (Fz for MMN, interval 96–136 ms, and Cz for P3a, interval 261–311 ms).

To determine the presence of the MMN and P3a components, a repeated measures ANOVA was conducted for each component separately with factors of condition (UNINF, INF, INF-DV) and stimulus type (H tone, M tone) measured at the electrode of greatest signal-to-noise ratio (Fz for MMN and Cz for P3a). Difference waveforms were calculated to compare amplitude across conditions. Where data violated the assumption of sphericity, degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity, and corrected p values reported. For post hoc analyses, when the omnibus ANOVA was significant, Tukey HSD for repeated measures was conducted on pairwise contrasts. Contrasts were reported as significantly different at $p<0.05$. All statistical analyses were performed using Statistica 12 software (Statsoft, Inc., Tulsa, OK).

2.5.3 Hypothesis testing—To assess effects of prior knowledge of the regularity of the sound sequence on auditory distraction, the behavioral responses and ERPs elicited by the H tones in the UNINF and INF conditions were compared. The INF-DV required a task involving the patterned sequence, whereas the INF condition did not. Thus, comparison between the INF-DV and INF condition allowed us to assess task effects on auditory distraction. The UNINF condition served as a control in that only implicit knowledge about the regularity of the sound sequence could possibly be obtained. It was neither relevant to the task nor indicated as a helpful feature for ignoring distracting effects of the H tone pitch change. Thus, explicit knowledge about the stimulus structure obtained in the INF and INF-DV conditions will indicate whether knowledge influences auditory distraction.

3. Results

3.1 Behavioral responses

Table 1 displays the HR, RT, and distraction effect for each stimulus type, in each condition.

3.1.1 Hit rate—Participants correctly identified significantly more tone durations when responding to pitch repetitions (M tones, p=0.87) compared to pitch changes (regular H or random L tones, p=0.79 and 0.77, respectively) (main effect of stimulus type: ($F_{1.58,20.54}$ =10.99, p=0.001, η_p^2 = 0.46). This included correct ‘no-go’ responses for the L tones in the INF-DV condition. There was no main effect of condition on HR ($F_{2,26}$ <1, p=.59), and no interaction between factors ($F_{4,52}$ <1, p=.85).

3.1.2 Reaction Time—Testing effects between the UNINF and INF conditions for all three stimulus types, responses were fastest to the M tones overall (main effect of stimulus type, $F_{1.47,19.14}$ =29.36, p<.0001, η_p^2 = 0.69). Post hoc calculations showed that RT, overall, was fastest to the regular M tone (477 ms). The RT to the fifth tone of the regular pattern (500 ms), the H tone, was significantly slower than the M tone, and significantly faster than the RT to the random L tone (545 ms). RT was slowest to the L tone. There was also a main effect of condition ($F_{1,13}$ =12.29, p=0.004, η_p^2 = 0.49), with overall significantly faster RT in the INF condition (496 ms) compared to the UNINF condition (519ms). There was no interaction between factors ($F_{2,26}$ <1, p=.54).

To test effects of implicit (UNINF) and explicit (INF and INF-DV) knowledge of the regularity of the H tone (terminal position of the five-tone pattern), the M and H tones were compared across all three conditions. There was a main effect of condition ($F_{1.32,17.19}$ =5.78, p<.021, η_p^2 = 0.31). Post hoc calculations showed that RT was significantly slower, overall, in the UNINF condition (499 ms) compared to INF (478 ms) and INF-DV (478 ms) conditions, with no difference between the informed conditions. There was a also a main effect of stimulus type ($F_{1,13}$ =13.98, p=0.002, η_p^2 = 0.52), due to a significantly faster RT overall to the regular M tone (473 ms) than the regular (pattern ending) H tone (497 ms).

3.1.3. Distraction Effect—There was no effect of condition on the behavioral distraction effect for the regular, pattern-ending H tone ($F_{2,26}$ <1, p=0.78), or the random L tone between the INF compared to the UNINF conditions (t_{13}<1, p=0.33) (Table 2). There was a significantly larger distraction effect between the overall mean of the L tones (M=68) and the overall mean of the H tones (M=25) (t_{13}=4.07, p=0.001).

3.2 ERP results

Figure 2 displays the mean ERPs evoked by the H and M tones. Figure 3 displays the mean H-minus-M-tone difference waveforms and the scalp voltage maps showing the topographical distribution for the MMN and P3a components. In the MMN latency range (at the Fz electrode), a negative deflection was observed peaking approximately 116 ms, with a fronto-central scalp distribution. A polarity inversion was observed at the mastoids, which is often observed when a nose reference is used (Vaughan & Ritter, 1970). In the P3a latency range (at the Cz electrode), a positive deflection was observed, peaking approximately 286 ms, having a more central scalp distribution than the MMN. Table 2 summarizes the mean difference waveform amplitudes of the ERP components.

3.2.1 MMN component—MMNs were elicited by the H tones in the UNINF and INF conditions but not in the INF-DV condition (Fig 3). This was statistically shown by a significant interaction between condition and stimulus type ($F_{1.52,19.72}$=4.49, p=0.033, η_p^2 = 0.26). Post-hoc calculations showed that the mean amplitude elicited by the H tone was significantly more negative than the mean amplitude elicited by the M tone, in the UNINF and INF conditions, but with no significant difference between H and M in the INF-DV condition. Moreover, there were no significant differences among the M tones (−1.19 μV_{UNINF}, −1.28μV_{INF}, −1.24μV_{INFDV}). Thus, the effects of condition on stimulus type were due to differences in response to the pattern-ending H tones. Post hoc calculations showed that the mean amplitude in the UNINF condition (−3.16 μV) was significantly more negative than in the INF-DV (−1.97 μV), but with no difference between the H-tone response in the UNINF and the INF (−2.67 μV). There was a main effect of stimulus type ($F_{1,13}$ =30.78, p<0.0001, η_p^2 = 0.70), with the overall H tone amplitude more negative than the overall M tone amplitude. There was also a main effect of condition ($F_{1.47,19.11}$=4.49, p=0.035, η_p^2 = 0.26). Post hoc calculations showed that the amplitude was smallest in the INF-DV condition than both other conditions. The overall mean amplitude between the UNINF and INF conditions (i.e., between the two conditions that significant MMNs were elicited) did not significantly differ. MMN was significantly elicited when the pattern regularity was not relevant to the task.

3.2.2 P3a component—P3a was elicited in all conditions (Fig 3) as revealed by a main effect of stimulus type ($F_{1,13}$=17.67, p=0.001, η_p^2 = 0.58) showing that the amplitude of the pattern-ending H tone was significantly more positive than the amplitude of the regular M tone. P3a amplitude was significantly larger in the UNINF condition (larger difference between the H and M tone amplitudes) than in the informed conditions (INF and INF-DV), demonstrated by a significant interaction between stimulus type and condition ($F_{1.35,17.6}$=5.19, p=0.027, η_p^2 = 0.29). Post hoc calculations showed a significantly more positive response to the H tone than M tone in the UNINF than in the INF and INF-DV conditions. Further, the interaction showed no significant differences among the M tones. There was also a main effect of condition ($F_{1.51,19.64}$=7.36, p=0.007, η_p^2 = 0.36). Post hoc tests showed that the amplitude was overall greater in the UNINF condition than the informed conditions, with no significant difference in amplitude between the INF and INF-DV conditions. This suggests an influence of explicit knowledge of the structural regularity on involuntary orienting indexed by P3a (significantly lower amplitude in the informed conditions).

4. Discussion

This study tested effects of task requirements and prior knowledge on auditory distraction by comparing the response to a pitch change (an irrelevant, distracting tone feature) occurring predictably in a tone sequence (every 5th tone) during several task conditions. Task conditions varied in what information the participant was given about the predictability of the pitch change (the irrelevant, distracting tone feature), and in the task that was to be performed.

Knowledge about the stimulus regularity did influence the distraction effect reflected in the amplitude of the P3a component, an index of orienting to the irrelevant feature of the stimulus input. P3a amplitude was significantly smaller when the participants' knew (were informed) about the tone sequence regularity compared to when they were not (when they were uninformed about the sequence regularity). The H tones occurred with the same regularity in all conditions, thus the reduction in amplitude in the informed conditions may be attributable to a lower distractibility that comes with explicit knowledge of its occurrence. This result indicates that for the P3a component, implicitly derived knowledge on its own did not abate distraction, but explicit knowledge did[2]. These results are consistent with Sussman et al. (2003) and Horváth et al. (2011), in which explicit knowledge abated behavioral and electrophysiological indicators of distraction by cueing. The current results

[2]It should be noted that we are not making a general conclusion but are specifically referring to effects of implicitly available information on P3a amplitude with respect to a regular pattern occurring in each condition. It is possible that implicit knowledge effects could be reflected in the P3a amplitude when comparing a regular sequence to the same sounds presented in random order.

thus extend those findings to explicit knowledge of predictability but without trial-by-trial cueing.

However, an interesting dissimilarity was found between behavioral distraction effects and neurophysiological distraction effects indexed by the P3a component (see also Berti, 2013; Chen & Sussman, 2013; Horváth, 2014; Munka & Berti, 2006; Parmentier, 2014; Wetzel, Schröger, & Widmann, 2013). The P3a amplitude, indexing orienting to the irrelevant pitch change (H-tone), was apparently reduced by knowledge (INF conditions) about its predictability. If the reduced amplitude of the P3a reflects less orienting to the irrelevant tone feature when the judgment task was being performed, this neurophysiologic finding would predict that behavioral distraction effects would also be lessened to the H tones in the informed (INF) conditions compared to the UNINF condition. However, the P3a amplitude did not fully reflect the behavioral result. This result differs from Sussman et al. (2003), in which the distraction effect was similarly reflected in both behavioral and P3a responses. However, there was a difference between the two paradigms. In Sussman et al. (2003), explicit visual cueing about the relevance of the irrelevant tone feature was presented immediately prior to each auditory stimulus, which may have effectively linked the tone response to the information that preceded it. Volosin and Horváth (2014) who found similar results as Sussman et al. (2003) also used a pre-cueing with a visual stimulus. In contrast, in the current paradigm, all knowledge about the irrelevant pitch change was part of implicitly derived information about the regularity of the sequence or was due to top-down knowledge about the tone sequence. There was no cueing of any type. Thus, without pre-cueing to the distracting stimulus, P3a may have reflected a difference between implicit and explicit knowledge that wasn't reflected in the behavioral response. Overall, the distinction between neurophysiologic and behavioral indices suggests that there are multiple processes converging that are not fully reflected in RT or HR, seeing as the responses occur after the ERP components are elicited.

There was no significant effect of explicit knowledge on the behavioral distraction effect. That is, there was no significant difference in the behavioral distraction effect induced by the pitch change of the H tone as a function of knowledge of the regularity of the H tone. One possibility is that there was no distinction between the implicit and explicit knowledge of the irrelevant regularity in terms of the amount of distraction. The regularity may have affected the amount of distraction in all conditions. This is supported by the significantly larger distraction effect to the L tones, which were all unpredictable, compared to the H tones, which were all predictable. This was seen as a slower RT and lower HR to the L tones compared to the H tones. This may be explained by the difference in presentation between the two tones. The H tone was predictable and the L tone was not. Thus, this behavioral result indicates that the patterned sequence (MMMMH) was detected implicitly, which may have had an effect on the speed of the response (RT) and on the accuracy (HR). However, there was also a difference in the probability of occurrence between the L and the H tones. Thus, an alternative explanation for this difference in distraction effect is that the H tone occurred more frequently and was thus less distracting than the L tone. Further data are needed to separate out factors of probability from predictability. The results of the current study cannot distinguish between these two possible interpretations.

One further consideration for interpretation of the results is that we used a within-subjects design and presented the conditions in a fixed order. This design was chosen as it is preferable for controlling for individual differences that may occur when testing effects across different independent variables, as each individual serves as their own control. Often in such situations, conditions are counterbalanced. However, we could not vary the order of conditions because to do so would cue participants into the tone sequence structure. That is, the UNINF condition had to be presented first to obtain a baseline measure of implicit knowledge of the sequence structure, prior to providing participants with the explicit knowledge about it. Notably, we did not find any evidence of carryover effects due to the fixed order. Separate statistical analyses showed no significant differences between responses in the first half and the second half of the conditions for the RT, MMN amplitude, and P3a amplitude. This suggests that the order of conditions did not contribute to our experimental effects.

The MMN component did not index distraction. The MMN was modulated by task-relevance, by relevance of the pattern to the deviance detection task, but not by knowledge of the regularity. MMN was significantly elicited when the pattern regularity was *not* relevant to the task. This finding is consistent with our previous studies showing that MMN is not modulated by the simple knowledge of the predictability of a stimulus (Sussman, Winkler, & Schröger, 2003; Rinne, Antila, Winkler, 2001) but is modulated when the information about stimulus regularity has task relevance, such as by altering the standard regularity (Sussman, Ritter, & Vaughan, 1998; Sussman et al., 2002; Sussman, 2007; Sussman, 2013). Knowledge of the regularity on its own, without relevance to the task, did not modulate MMN.

In contrast, pattern-task-relevance had no effect on the P3a amplitude. There was no further reduction of the P3a amplitude when the pattern was task-relevant (in the INF-DV condition) compared to when it was not task relevant (INF condition). The response to the H-tone that evoked an involuntary orienting of attention reflected by P3a is apparently not reliant on the standard formation process of change detection reflected by MMN. This indicates that the P3a and MMN stem from different neural substrates, and are modulated by different cognitive processes (Horváth et al., 2008; Chen & Sussman, 2013). The absence of MMN was due to maintenance of the representation of the regularity used to perform the pattern task, as only in the INF-DV condition was the H tone relevant to the repeating standard. If subjects only withheld the response to the lowest tone without monitoring the pattern, then MMN should have been elicited by the H tone in the INF-DV condition. The absence of MMN to the H tone in the INF-DV condition thus indicates that the pattern task was being tracked and is consistent with our previous study using this paradigm (e.g., Sussman et al., 2002). Nonetheless, some orienting to the H tone (some distraction by the pitch change) still occurred despite knowledge of the predictability of the H tone. These results suggest that predictability on its own is not enough to fully abate the distracting effect of a pitch change. Only when the irrelevant, distracting features were reliably cued in advance (e.g., visually cued 250 ms in advance, Sussman et al., 2003) did we observe both the behavioral distraction effect and the P3a component abolished.

4.1 Conclusions and summary

Explicit knowledge of the sequence structure modulated distraction effects indexed by the P3a component. P3a was largest in the UNINF condition (no explicit knowledge) and significantly smaller when subjects were informed about the occurrence of the irrelevant pitch change (INF, IN F-DV) in the regularity of the tone pattern (MMMMH). However, there were distinctions in distraction effects reflected by the neurophysiological (P3a) and behavioral measures (see also Chen & Sussman, 2013; Wetzel, Schröger, & Widmann, 2013). The P3a was only modulated by explicit knowledge of the structural regularity, whereas there was no significant difference between explicit and implicit knowledge on distraction effects indexed by behavioral measures. This difference may at least in part be due to the nature of how the knowledge was delivered to the participant during the course of response requirements (e.g., top-down knowledge vs. cueing paradigm). The amount of behavioral distraction was reduced to the H tone (predictable) compared to the L tone (unpredictable) overall, suggesting that implicit and explicit knowledge of the stimulus regularity abated the behavioral distraction effect. The MMN component was only modulated by task requirements and not by stimulus predictability as such. Taken together, our results show differential effects of knowledge and predictability on distraction effects indexed by P3a and behavioral measures.

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Highlights

- Implicit and explicit knowledge of the stimulus regularity abated the behavioral distraction effect
- Explicit knowledge about the stimulus regularity modulated the P3a amplitude
- P3a and behavioral indices of distraction were not fully concordant
- MMN was modulated by task-relevance; P3a was not.
- MMN did not index distraction effects

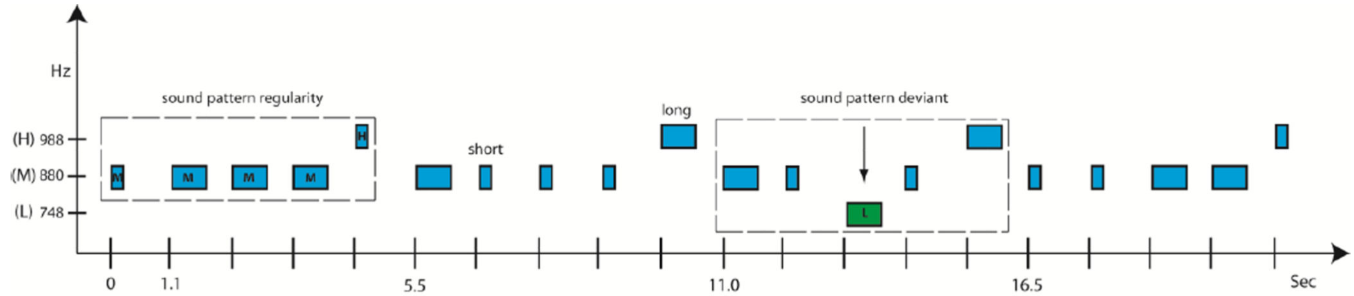

Figure 1.

Schematic diagram of the experimental paradigm. Rectangles represent tones. Frequency is depicted on the y-axis. Time (in seconds) is depicted on the x-axis. Blue rectangles delineate the repeating regular five-tone pattern of medium-pitched (M) and high-pitched (H) tones (denoted with the dashed line). The width of the bars depicts tone duration (short and long). The green rectangle is the low-pitched (L) tone that is presented randomly and creates a pattern deviant (task-relevant for the INF-DV condition). Tones were presented once every 1.1 s. Participants discriminated sound duration in all conditions (two-alternative forced-choice task) by pressing one of two response keys.

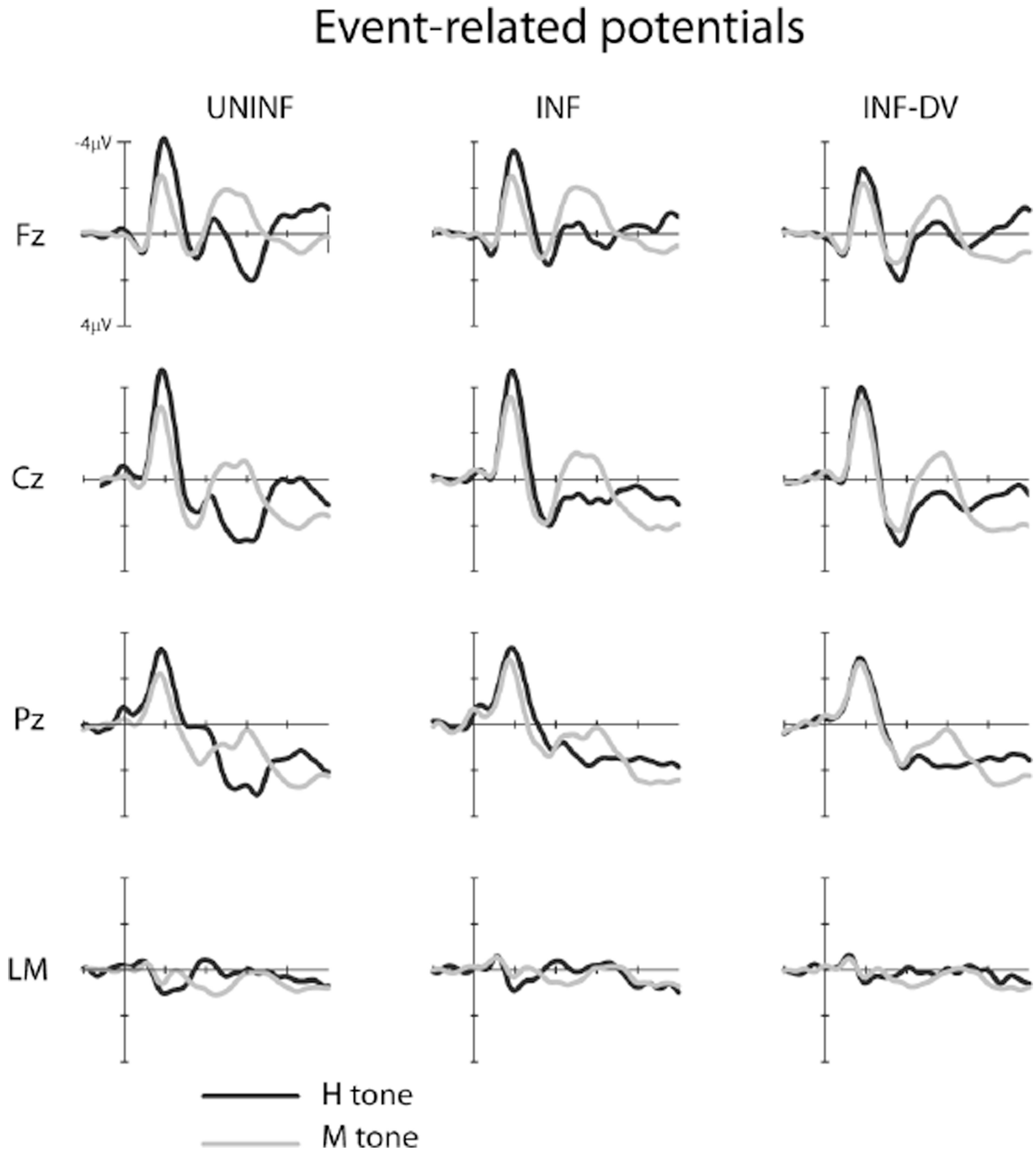

Figure 2.

Event-related brain potentials (ERPs) elicited by the M (gray line) and H (black line) tones of the five-tone pattern (MMMMH) for the *Uniformed* (UNINF, left column), *Informed* (INF, middle column), and *Informed-Detect Pattern Violation* (INF-DV, right column) conditions displayed for the Fz (top row), Cz (second row), Pz (third row), and Left Mastoid (LM, bottom row) electrodes. Clear P1, N1, and P2 peaks were elicited by both M and H tones in all conditions.

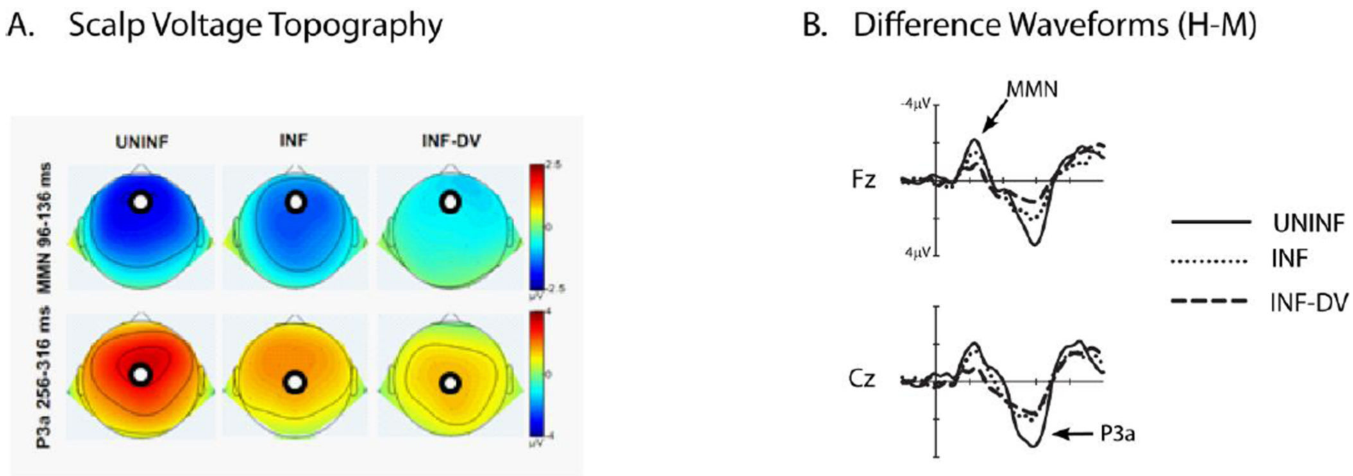

Figure 3.
Difference Waveforms (ERPs elicited by the M tone are subtracted from the ERPs elicited by the H tone). A. Scalp voltage topography of the difference waveforms is displayed for each condition (UNINF, INF, and INF-DV) at the peak latency of the MMN (top panel) and P3a (bottom panel) components. The black circle depicts the Fz electrode location. B. Difference waveforms are overlain separately at the Fz (top row), Cz (second row), Pz (third row), and LM (bottom row) electrodes for the UNINF (solid, black line), INF (dotted line), and INF-DV (dashed line) conditions. The MMN peak is labeled with an arrow at the Fz electrode and the P3a peak is labeled with an arrow at the Cz electrode (greatest S/N ratio, respectively).

Table 1

Behavioral data

Condition	Stimulus	HR	RT	Distraction Effect
Uninformed (UNINF)	M	.87 (7)	487 (66)	(H–M) 23 (25)
	H	.79 (12)	510 (70)	(L–M) 72 (44)
	L	.77 (11)	559 (97)	
Informed (INF)	M	.89 (5)	467 (64)	(H–M) 23 (27)
	H	.80 (12)	489 (71)	(L–M) 65 (44)
	L	.77 (10)	531 (95)	
Informed-Detect Violation (INF-DV)	M	.86 (8)	463 (64)	(H–M) 28 (39)
	H	.77 (16)	492 (67)	
	L	.78 (14)*	--	

Mean hit rate (HR), reaction time (RT) in milliseconds and distraction effect in milliseconds
M=frequent regular (880 Hz) tone; H=infrequent regular (988 Hz) tone; L= rare random (748 Hz) tone

*HR = correct rejection (no-go).

Standard deviation in parentheses.

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Table 2

Difference waveforms (ERP to H-tone minus ERP to M-tone). Mean amplitude [in μV] (standard error of the mean in parentheses) (interval used for statistical measurement in parentheses).

Component	Condition	Electrode		
		Fz	**Cz**	**Pz**
MMN (96–136 ms)	UNINF	−1.97 (0.36)	−1.86 (0.31)	−1.15 (0.29)
	INF	−1.39 (0.32)	−1.51 (0.31)	−1.2 (0.24)
	INF-DV	−0.73 (0.34)	−0.62 (0.37)	−0.33 (0.35)
P3a (256 – 316 ms)	UNINF	2.99 (0.71)	3.21 (0.72)	2.14 (0.61)
	INF	1.83 (0.53)	1.78 (0.60)	1.27 (0.58)
	INF-DV	1.04 (0.44)	1.54 (0.50)	1.37 (0.42)