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Category effects: Is top-down control alone sufficient to elicit the mismatch negativity (MMN) component?

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Abstract

This study investigated whether the mismatch negativity (MMN) event-related brain potential (ERP) could be evoked by purely top-down, attentional control. An infrequently occurring tone was designated as a target prior to presenting a randomized sequence of five equi-probably occurring tones. MMN elicitation to the tones categorized as "high", "medium", or "low" frequency, and designated as the target, would indicate that the change detection process can be driven solely by top-down control. However, MMNs were not elicited by the categorized tones. Only the N2b and P3b attention-driven target detection components were elicited. These results suggest that top-down factors alone cannot generate mismatch negativity. Standard formation by stimulus-driven factors is required.

Keywords

Top-down control; Attention; Mismatch negativity (MMN); Categorization

Introduction

Categorization of auditory input allows us to rapidly make sense of what is happening around us and react in an appropriate way. Identification of important environmental sound events is accomplished first by ascertaining the sound context of our surroundings, and then by establishing specific auditory regularities as the norm. Subsequent stimuli that are detected as different from these established regularities elicit an event-related brain potential (ERP) called the mismatch negativity (MMN). The MMN indexes how sounds are represented in auditory memory because the change detection process is based upon pattern detection (Sussman, 2007). According to the proposed model of the MMN system by Sussman (2007), the organization of the sounds and the standard formation phases occur prior to the deviance detection phase. The 'standard', which reflects a repeating pattern of stimulus features extracted from an acoustic signal, is designated andneurophysiologically represented in auditory memory (Haenschel, Vernon, Dwivedi, Gruzelier, & Baldweg, 2005; Näätänen, 2003; Sussman, 2007; Sussman, Sheridan, Kreuzer, & Winkler, 2003). Stimulus-driven and attention-based factors are involved to form this template (Elhilali, Xiang, Shama, & Simon, 2009; Rinne, Sampo, & Winkler, 2001; Ritter, Sussman, Deacon, Cowan, & Vaughan, 1999). Deviance detection occurs after the established regularities of the ongoing input are determined. The subsequent deviance detection process can occur with or

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without attention (Gomes, Molholm, Ritter, Kurtzberg, Cowan, & Vaughan, 2000; Näätänen, 2000; Sussman, Ritter, & Vaughan, 1998). We investigated the ability of the mismatch system to form standards (non-targets) and distinguish deviants (targets) among multiple equi-probably occurring tones that differ only in tone frequency. The main objective of this study was to evaluate whether top-down (attentional) control can generate an MMN on its own, without relying on bottom-up, or stimulus-driven factors for standard formation.

Previous studies have shown attentional influence on the elicitation of MMN. When participants were presented with identical stimuli and instructed to assess them in two different ways, MMN was generated according to the task demands that altered the repeating standard in the different conditions (Sussman, Winkler, Huotilainen, Ritter, & Näätänen, 2002). The sound sequence contained a repeating pattern of two tones (XXXXOXXXXO… and so on), where 'O' had a higher frequency value than 'X'. A third tone (T) with a lower frequency than the 'X' and 'O' tones occurred rarely, randomly replacing the 'X' tone 2% of the time (e.g., XXXXOXXTXOXXXXO). In one condition, participants focused their attention to the pitch of the sounds, responding to the T tones. In another condition, they were instructed to detect the repeating five-tone pattern (XXXXO…), hold it in memory, and respond when a rare pattern deviant was detected, which was created by the T tone. Thus, in both conditions, the 'T' Tone was the target and the 'O' tone was the dependent measure. MMN was elicited by the 'O' tones when detecting pitch deviants but not when detecting pattern deviants. This is because when the task required pattern discrimination, the 'O' tone was part of the repeating pattern (the standard), it was not deviant and thus did not elicit MMN. However, when the task required pitch discrimination, the frequently occurring 'X' tone was the standard from which both the 'O' tone and the 'T' tone were pitch deviants and both elicited MMNs. Attention modulated the standard representation, not the deviant. These findings indicate that attention can modulate MMN elicitation by altering the standard representation (i.e., how the sounds are organized in memory), which then serves as the basis for deviance detection.

The role of attention in modifying the neural representation used in the change detection process is also seen in more complex situations (Sussman et al., 1998). Sussman et al. (1998) alternated a sequence of three high and three low tones, which were ignored by participants in one condition and selectively attended in another. When participants ignored the sounds, segregation of the high and low sounds did not occur, and thus no MMN was elicited by within-stream pattern deviants. In contrast, when subjects selectively attended to the higher frequency tones and identified the within-stream 3-tone pattern, MMNs were elicited by the pattern reversal deviants. Segregation of the tones into two separate streams came about due to attention, in turn producing MMNs in both the attended and the unattended streams. Further, the attention-based P3 component (Sutton, Braren, Zubin, & John, 1965) was elicited by attended deviants but not unattended ones, indicating that participants were successfully selectively attending the high tones. The elicitation of MMN in the attended but not ignore condition indicates the ability of attention to segregate the high from low tones. The segregation of the tones, in turn, modulated standard formation which altered the neural trace. MMN elicitation was concordant with the reorganization of sounds used to perform the task.

Top-down factors, therefore, have been shown to modify initially stimulus-driven auditory organization, to modify the standard that forms the basis for deviance detection, such that the MMN is elicited. BUT, can MMN be generated by purely top-down factors, without stimulus-driven support? The most common manner in which stimuli are arranged to elicit the MMN is to have an infrequent deviant tone embedded in a sequence of identical standard tones, where an acoustic attribute, such as pitch, distinguishes the standard from the deviant tones. A more complicated way requires that the MMN system identifies a combination of tones as the standard even though the tones constantly vary, for example in pitch or intensity. An example would be that pairs of tones usually rise in pitch from the first to the second tone, with an infrequent deviant consisting of a pair of tones that descend in pitch from the first to the second tone (Saarinen, Paavilainen, Schröger, Tervaniemi & Näätänen, 1992; Paavilainen, Degerman, Takegata, & Winkler, 2003). Note that in this case, in contrast to the common way of eliciting the MMN, the tones that comprise the standards differ from one another. However, there is still an acoustic pattern that distinguishes the standard pairs from the deviant pairs. It has been shown that the P3 component, which is sensitive to stimulus probability, has the same amplitude for a single non-target word as for several non-target words having the same overall probability but all belonging to the same semantic category (Friedman, Simson, Ritter, & Rapin, 1975). In the current experiment, five tones all differing in pitch were presented equiprobably. The question was whether the auditory system would group the non-targets as ‘standards’ such that MMN would be elicited by the infrequent target, even if there were no acoustic pattern shared by the non-targets other than that they differ in pitch from the target. That is, attention would be used to ‘organize’ the sounds to represent a frequent-to-infrequent relationship among the tones. The key here is that there is no stimulus-driven factor to induce the frequent-to-infrequent relationship. The tones are distinct from one another, not to be construed as small variations of one standard tone (Winkler, Paavilainen, Alho, Reinikainen, Sams, & Näätänen, 1990). Thus, the frequent-to-infrequent relationship can only be derived by top-down factors. If MMN is elicited by the target sounds it would suggest that attention affected the deviant phase of the MMN process (Sussman, 2007), which to date has not been directly tested. Frequency Oddball conditions were also conducted for comparison, to show the MMN elicited by the target tones when stimulus-driven factors drove regularity detection. In the Oddball conditions, the MMN elicited by the target tones was expected to show typical MMN topography, with an inversion at the mastoid.

Methods

Participants

Eleven adults between the ages of 17 and 30 years (*M*= 25, SD = 4; 7 males) participated in the experiments. Participants passed a hearing screening (20 dB HL, 500, 100020 dB HL, 500, 2000, and 4000 Hz in both ears), and did not have any reported neurological disorders. All participants gave written informed consent after the procedures were explained to them, and were paid for their involvement in the study.

Stimuli and Procedures

Five-Tones Experiment—A schematic of the stimulus paradigm is shown in Figure 1 (top panel). Ten of the subjects participated in the main experiment (*M* = 24 years, SD = 5; 6 males), seated in a comfortable chair in a sound-attenuated booth (IAC, Bronx, NY), presented with sounds, bilaterally, through insert earphones (EAR-tones, Indianapolis, IN). The stimuli were five pure tones: 440 (A_4), 554 ($C^{\#}_5$), 698 (F_5), 880 (A_5), and 1109 ($C^{\#}_6$) Hz. Each tone was 200 ms in duration (7.5 ms rise/fall time) with an intensity value of 80 dB SPL, calibrated using a Brüel & Kjær sound level meter (model 2200) with an artificial ear. The stimuli were created using Adobe Audition software and were presented using Neuroscan Stim software and hardware (Compumedics Corp, Charlotte, NC). The five tones were randomized and presented equiprobably (p=.20) in a total of nine blocks of 300 stimuli (60 of each tone) with a stimulus onset asynchrony (SOA) of 800 ms. Figure 1 (top panel) provides a schematic of the paradigm.

There were three conditions (*High*: 1109 Hz; *Medium*: 698 Hz; and *Low*: 440 Hz). The nine stimulus blocks were randomly presented and the conditions (3 blocks each) were randomly assigned across participants using a Latin Squares design. Participants were instructed to press the response key to the designated target in each condition separately. Thus, in the "High" condition, the target was the highest frequency (1109 Hz) tone, which occurred 20% of the time randomly in the block. A practice block was provided prior to each condition for practice of the designated target tone. The experimental session lasted approximately 1.5 hours, including breaks and electrode placement and removal.

Oddball Control—Oddball conditions (Fig 1, bottom) were conducted with four of the subjects (M = 26 years, SD = 3; 1 male), three of which also participated in the main experiment. One of the participants' data was excluded due to excessive artifact. The data from the remaining three participants were used for display. The same procedures were used as for the main experiment with the following modifications. Stimuli were presented in an oddball paradigm in three conditions that matched the target stimuli of the Five-Tones experiment (High, Medium, and Low conditions). The High and Low Oddball conditions consisted of three blocks, each with 300 stimuli. For the High oddball, the 1109 Hz was the target (p=.2) and the low frequency tones (440 Hz) were the frequently presented sounds (p=.8). For the Low oddball, the 440 Hz tone was the target (p=.2) and the 1109 Hz tones were frequently presented (p=.8). Participants were instructed to press the response key for the infrequent high or low frequency tone in their respective conditions. For the Medium Oddball condition, in half of the runs the target was the 698 Hz tone (p=.2) and the standard (p=.8) was the 554 Hz tone, and in the other half, the roles were reversed (698 Hz, p =.8; 554 Hz, p=.2). Conditions were counterbalanced across subjects, using a Latin Square Design. In all conditions, participants were instructed to respond to the tone that occurred less frequently. The experimental session lasted 1.5 hours, including breaks and electrode placement and removal.

Electroencephalogram (EEG) Recording and Data Analysis

EEG was recorded from 32 electrode sites using an electrode cap: FPz, Fz, Cz, Pz, Oz, FP1, FP2, F3, F4, F7, F8, FC5, FC6, FC1, FC2, T3, T4, C3, C4, CP5, CP6, CP1, CP2, T5, T6, P3, P4, O1, O2, LM, and RM. The nose was used as the reference. Horizontal electro-oculogram was recorded between F7 and F8 in a bipolar configuration, and vertical electro-oculogram with FP1 and an electrode placed below the left eye. The impedance was kept below 5 k'Ω. EEG was recorded 0.05–100 Hz with a sampling rate of 500 Hz.

Offline filtering was done with a low pass of 20 Hz, and 24dB/octave roll-off. Epochs started 100 ms before and ended 600 ms after stimulus onset. Rejection criteria excluded epochs exceeding ±75 μV from any channel after the epochs were baseline corrected. This resulted in approximately 10% rejection of the epochs per stimulus type. Epochs were then averaged, separately for each stimulus type and condition. For the Medium condition of the Five-Tones experiment, only the ERP responses to correct targets were averaged together due to the low hit rate. This was not necessary for the High and Low conditions because of the high hit rate (HR).

To delineate the MMN, N2b, and P3b components in the Five-tones conditions, ERPs elicited by the target tones were subtracted from the same physical tones obtained in the conditions they were non-targets. For example, the ERP response to the 1109 Hz tone in the High conditions which was the target ('deviant') was compared with the ERP response to the 1109 Hz tones in the Medium and Low conditions when it was a non-target ('standard'). Thus, the 'standard' comparison tone had both the same physical and probabilistic parameters as the target tone. In the Oddball conditions, the non-target tones with the same physical parameters as the targets (deviants) were used for comparison to delineate the MMN, N2b, and P3b components. MMN was not visually observed in the difference waveforms of the Five-tones conditions (Fig. 4) and no further analysis was conducted.

Peak latency of the N2b, and P3b components (Table 2) were determined using a peak-detection program (Neuroscan, Compumedics) from the electrode with the highest S/N ratio for each component (Cz and Pz, respectively). The amplitudes of the N2b, and P3b components were measured, relative to the 100 ms pre-stimulus baseline, using the mean amplitude of each individual participant for each stimulus type in a 40-ms interval centered on the grand mean peak of the difference waveforms at Cz, and Pz, where the respective components are known to have the greatest signal-to-noise ratio.

Behavioral data were analyzed by calculating hit rate (HR), false alarm rates (FAR), and reaction times (RT) to the designated target in each condition. Responses were considered correct if they fell between 200 and 900 ms from stimulus onset. Repeated measures analysis of variance (ANOVA) was used to compare HR, FAR, and RT, separately, across the conditions of the Five-Tones experiment, with.

The mean amplitude of the N2b and P3b components elicited in the Five-Tones conditions was compared using repeated measures ANOVAs with factors of condition (High, Medium, and Low), stimulus type (target, non-target) and electrode (Fz, F3, F3, Cz, C3, C4, Pz, P3, P4) to determine presence and topographic distribution of the ERP components. In addition, two-way repeated measures ANOVAs were conducted on the difference waveforms with factors of condition and electrode (Cz, C3, C4 for N2b, and Pz, P3, P4 for P3b) to statistically compare the amplitude and latency of the components across conditions of the Five-Tones experiment. Post hoc analyses were calculated using Tukey HSD. Greenhouse-Geisser corrections were used and are reported.

For the Oddball conditions, the mean amplitude and peak latency of the MMN, N2b, and P3b components are reported in Tables 1 and 2. No further statistical analyses were conducted for the Oddball experiment.

The peak obtained from the grand mean difference waveforms for the MMN, N2b, and P3b components were used to display the voltage maps (Fig. 5).

Results

Behavioral results

Table 1 displays the HR, FAR, and RT for all conditions. On average, subjects were better at detecting the target when it was the highest tone (.90) or the lowest tone (.89) compared to when it was the middle frequency tone (.42). In the Five-Tones experiment, there was a main effect of condition on HR ($F_{2,\,18} = 35.52$, $p < 0.001$) and a main effect of condition on FAR ($F_{2,18} = 22.26$, $p < 0.0001$). Post hoc tests showed that the HR and FAR were not significantly different from each other in the High and Low conditions, but both were significantly higher than the HR and FAR of the Medium condition. There was also a main effect of condition on RT ($F_{2,\,18} = 57.62$, $p < 0.001$). Post hoc analysis revealed that RT was shortest for the High condition (401 ms), longest for the Medium condition (504 ms), and intermediate for the Low condition (428 ms).

ERP results

Table 2 displays the mean peak amplitudes and latencies for the MMN, N2b and P3b components in each condition of the Five-Tones and Oddball experiments. Figure 2 displays the corresponding ERPs elicited by the target and comparison tones for each condition of the

Five-Tones experiment, and Figure 3 displays the corresponding ERPs elicited by the target and comparison tones for each condition of the Oddball Control experiment.

Five-Tones Experiment—Clear N1 components were evoked by target tones and respective comparison tones (non-targets) in each condition (Fig 2). A typical MMN was not visually observed in any of the conditions. In contrast, typical looking N2b and P3b components were elicited by designated target tones. For the negativity occurring in the range of the N2b component, there was a main effect of stimulus type ($F_{1, 9} = 9.49$, $p < 0.01$), with post hoc tests showing that the ERP evoked by the target stimulus was more negative than that evoked by the non-target stimulus. There was a trend toward a main effect of electrode but it did not reach significance after correcting for sphericity (p=0.15). There was an interaction between stimulus type and electrode ($F_{8, 72} = 6.68$, $p < 0.003$), with post hoc analysis of the interaction showing that target responses were largest at the Cz electrode, consistent with the N2b scalp topography. There was no main effect of condition, and no other significant interactions.

Presence of the P3b component was confirmed by a main effect of stimulus type ($F_{1, 9} = 34.22$, $p <0.001$), with the target response greater (more positive) than the non-target, and a parietal scalp distribution (main effect of electrode, $F_{8, 72} = 14.39$, $p < 0.001$), with the greatest amplitude at the parietal electrodes. There was also an interaction between stimulus type and electrode ($F_{8, 72} = 23.14$, $p < 0.001$), with post hoc calculations showing that there were significant differences between target and non-target stimuli at central and parietal electrodes only (consistent with the parietal distribution of the P3b component).

Figure 4 displays the difference waveforms at the Fz (top row), LM (second row), Cz (third row), and Pz (bottom row) electrodes, separately for the high (left column), medium (middle column), and low (right column) target tone conditions. Figure 5 displays the difference waveforms by experiment (Five-Tones top panel, Oddball bottom panel) along with the voltage maps at the corresponding peaks for each component. There was no main effect of condition for the N2b amplitude. There was a main effect of condition for the P3b amplitude ($F_{2,18} = 4.75$, $p < 0.05$). Post hoc tests revealed that P3b amplitude was larger when evoked in the High and Low conditions than by the Medium condition. P3b was also largest at the midline parietal (Pz) electrode (main effect of electrode, $F_{2, 18} = 9.09$, $p < 0.002$). There were no other main effects or interactions on the N2b or P3b amplitude.

For latency of the components, there was a main effect of condition on the N2b latency ($F_{2,18} = 31.41$, $p < 0.001$), with post hoc tests showing that latency was longest in the Medium condition. There was also a main effect of condition on the P3b component ($F_{2,18} = 47.37$, $p < 0.05$), with post hoc calculation showing that P3b latency was shortest when the high tones were targets (high condition). Smaller amplitude and longer latency found in the Medium condition for the N2b/P3b components is consistent with target detection being more difficult for the middle frequency of the five different tones.

Oddball Control Experiment—Clear N1 components were evoked by target tones and respective comparison tones (non-targets) in each condition (Fig 3). A clear negative displacement of the ERPs evoked by the target compared to the ERP evoked by the non-target can be seen, with the largest difference at the Fz electrode. This difference represents the MMN component (which is displayed in Figs 4 and 5 in the difference waveforms). The MMN peaks earlier in the High and Low Oddball conditions compared to the Medium Oddball condition, which is consistent with greater difficulty identifying the middle tone, though this difference was not statistically confirmed. The P3b component was clearly observed in all conditions, and appears to be larger than that elicited by targets in the Five-Tones conditions. The N2b component is not as clearly demarcated in the Control Oddball conditions as in the Five-tones conditions, which appears to be due to its riding up on the large positive-going P3b component. Note the clear inversion in polarity at the mastoid trace that denotes the MMN component of the Oddball conditions, whereas there is no such inversion at the latency of the clear negative peak in the Five-tones conditions (Fig 4).

Discussion

The results of this study suggest that MMN cannot be elicited by top-down factors alone. MMNs were not obviously elicited by tones that occurred 20% of the time within a stimulus block when they were designated as targets. This indicates that there was a failure to override the stimulus-driven sound organization of standard formation, preventing automatic deviance detection of the target, and consequently, no MMNs were elicited in any of the Five-tones conditions. That is, no standard could be established from which the designated target would be automatically detected as a deviant when the target tones occurred with the same probability as the other tones in the sequence. In contrast, the same target tones occurring with 20% random probability did elicit MMN when the stimulus-driven parameters of the sequence had a clear standard-deviant (infrequent-to-frequent) relationship (80–20%) with the target in the Oddball conditions. Thus, together these results suggest that stimulus-driven factors, such as a frequent-to-infrequent ratio of the stimuli or of a repetitive pattern, must be able to convey adequate information to establish a standard from which an infrequently occurring sound or pattern of sounds will automatically be detected as deviant. That is, successful identification of a tone as an infrequent and randomly occurring target (evidenced by elicitation of the N2b and P3b components) is not enough to set up the basis for the standard-deviant relationship used in the automatic change detection process.

Alternatively, the absence of an observable MMN in the Five-tones conditions may be due to an overlap of the MMN component with the N2b. The target detection task in the Five-tones conditions was considerably more difficult than the corresponding tasks in the Oddball conditions. The difficulty of the target detection task may have increased the latency of the MMN such that it partially overlapped with the N2b, and may have decreased its amplitude. Although we did not find solid evidence for this alternative explanation, because we would expect a clear inversion at the mastoid for a simple frequency deviant in the Five-tones conditions as was clearly present in the Oddball conditions (Fig 4), the alternative explanation cannot be completely ruled out by this one set of data. There are no other studies that we are aware of that were designed to distinguish between top-down and stimulus-driven factors on the automatic change detection process.

In the current study, top-down control alone did not alter the automatic deviance detection system. Another way to view the current results is to suggest that MMN does not reflect categorization of sounds. That is, the purely top-down designation of a tone as belonging to an infrequent category (e.g., “high frequency”) among other tones is not enough to set up the standard-deviant relationship required for the automatic change detection process leading to MMN elicitation.

These data suggest that there cannot be attentional influence on the deviant itself, in the sense that designation of a tone as a deviant is not enough to establish a standard without the stimulus-driven characteristics of the standard to support the process. These data are consistent with Sussman’s (2007) model of MMN, in which the basis for MMN is standard formation. Thus, MMN elicitation is dependent upon stimulus-driven factors, even when attention can modify the standard used in the MMN process. Attention cannot be used to designate the deviant, without a stimulus-driven basis for it. The results indicate that the automatic change detection process is dependent upon the stimulus statistics of the auditory scene.

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Highlights

- Top-down control alone is not sufficient for generating MMN component.
- Intent-based auditory discrimination is not enough to establish a standard without a stimulus-driven basis for it.
- Stimulus-driven factors must contribute to standard formation for MMN elicitation.
- The automatic change detection process is dependent upon the stimulus statistics of the auditory scene

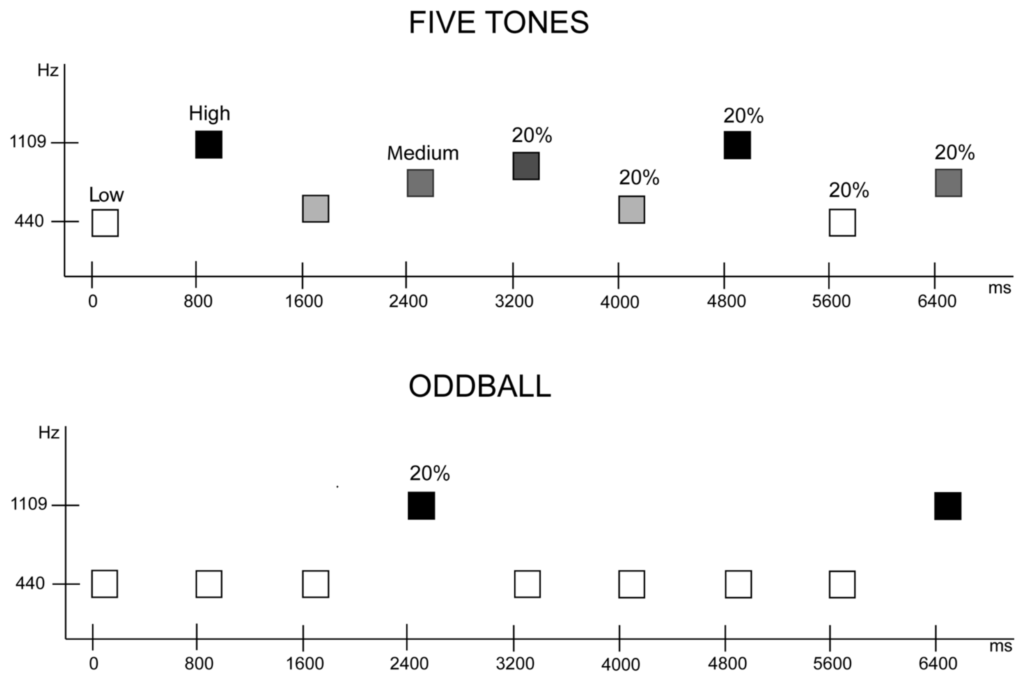

Figure 1.
Schematic diagram of the stimulus paradigm. Five-Tones experiment (top panel) consisted of five equiprobable (*p*=*.2*) tones presented randomly. Target tones for each condition (High, Medium, and Low) are labeled. The Control Oddball conditions the target tones of the Five-Tones Experiment were presented separately (*p*=.2) in an oddball condition with a frequent (*p*=.8) tone.

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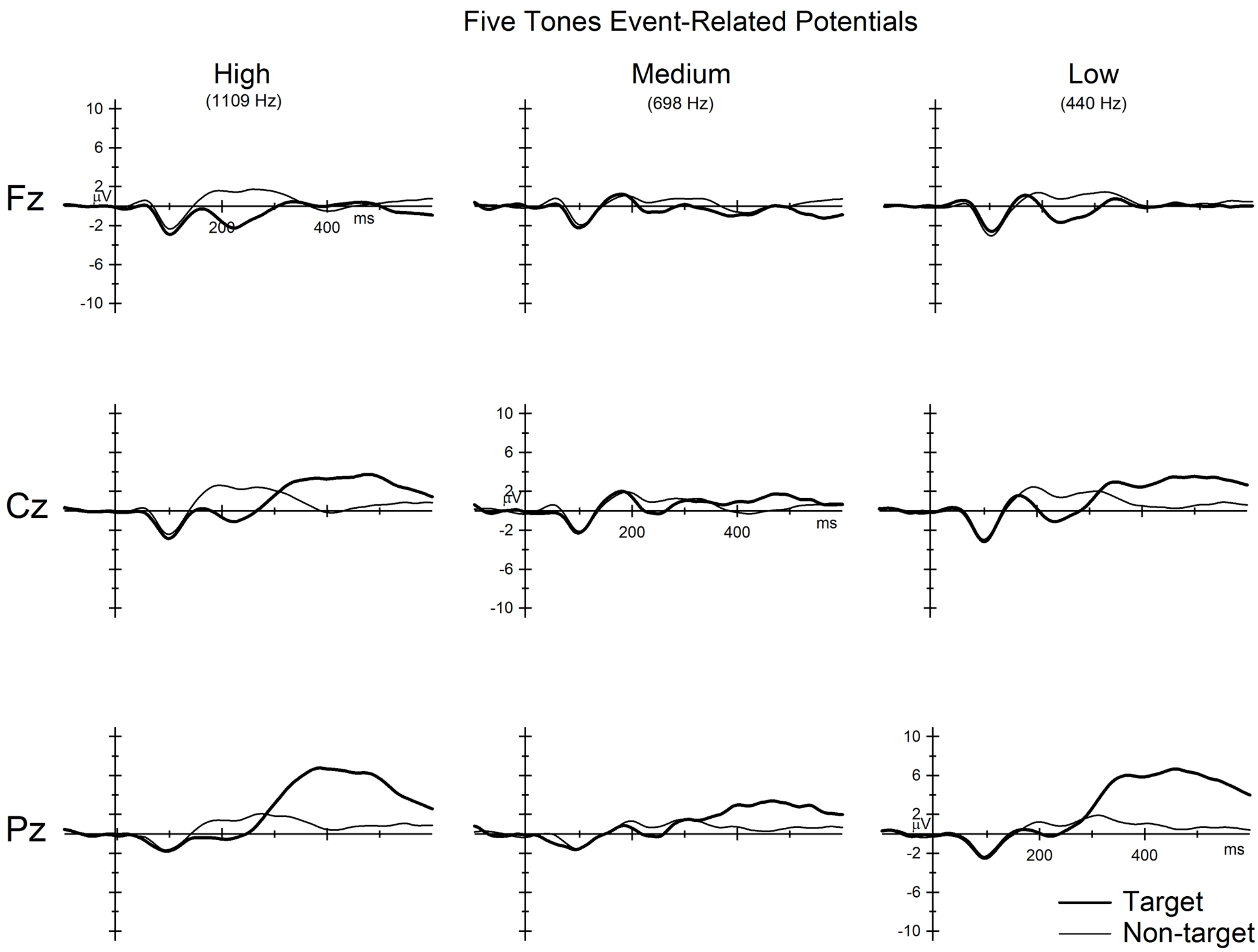

Figure 2. Five-Tones experiment

Event-related potentials elicited by targets (thick line) and non-targets (thin line) are displayed at Fz, Cz, and Pz electrodes for the High (left column), Medium (middle column) and Low (right column) conditions.

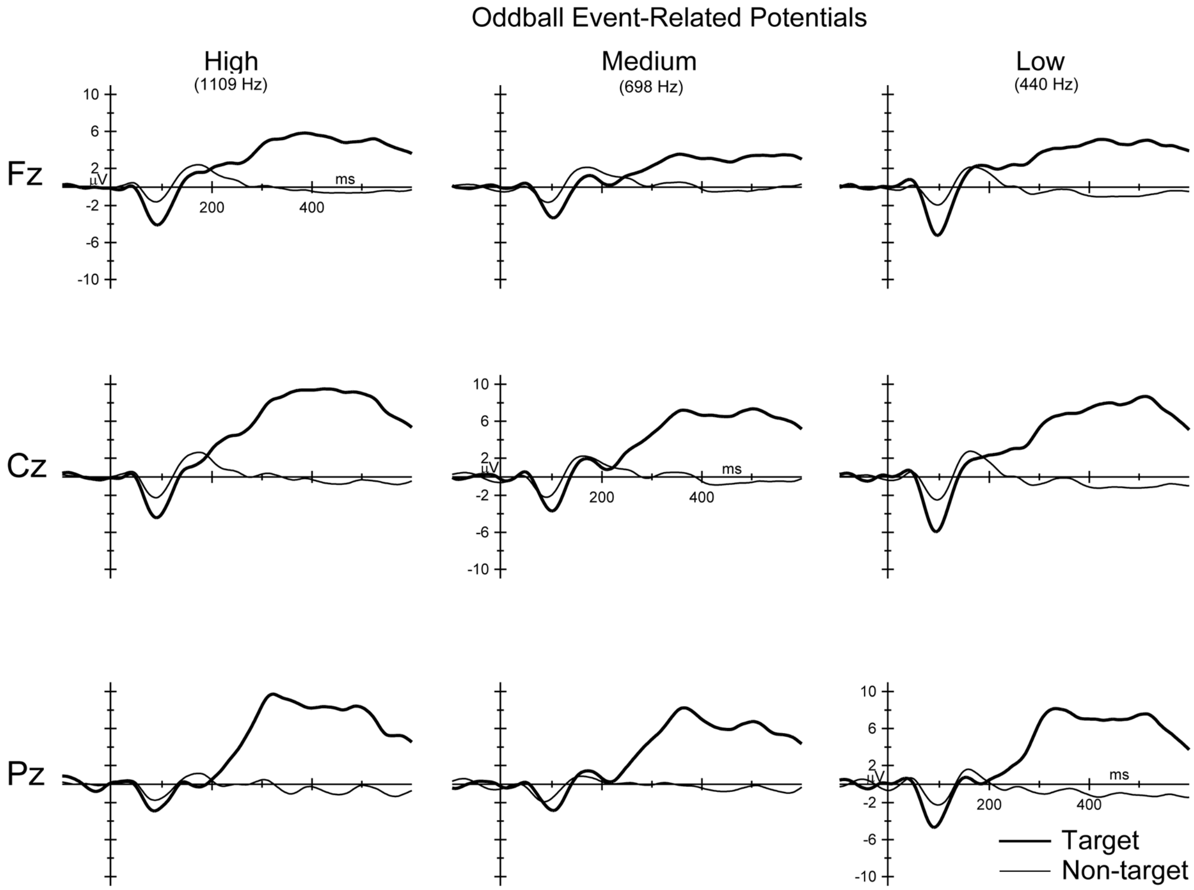

Figure 3. Control Oddball experiment

Event-related potentials elicited by targets (thick line) and non-targets (thin line) are displayed at Fz, Cz, and Pz electrodes for the High (left column), Medium (middle column) and Low (right column) conditions.

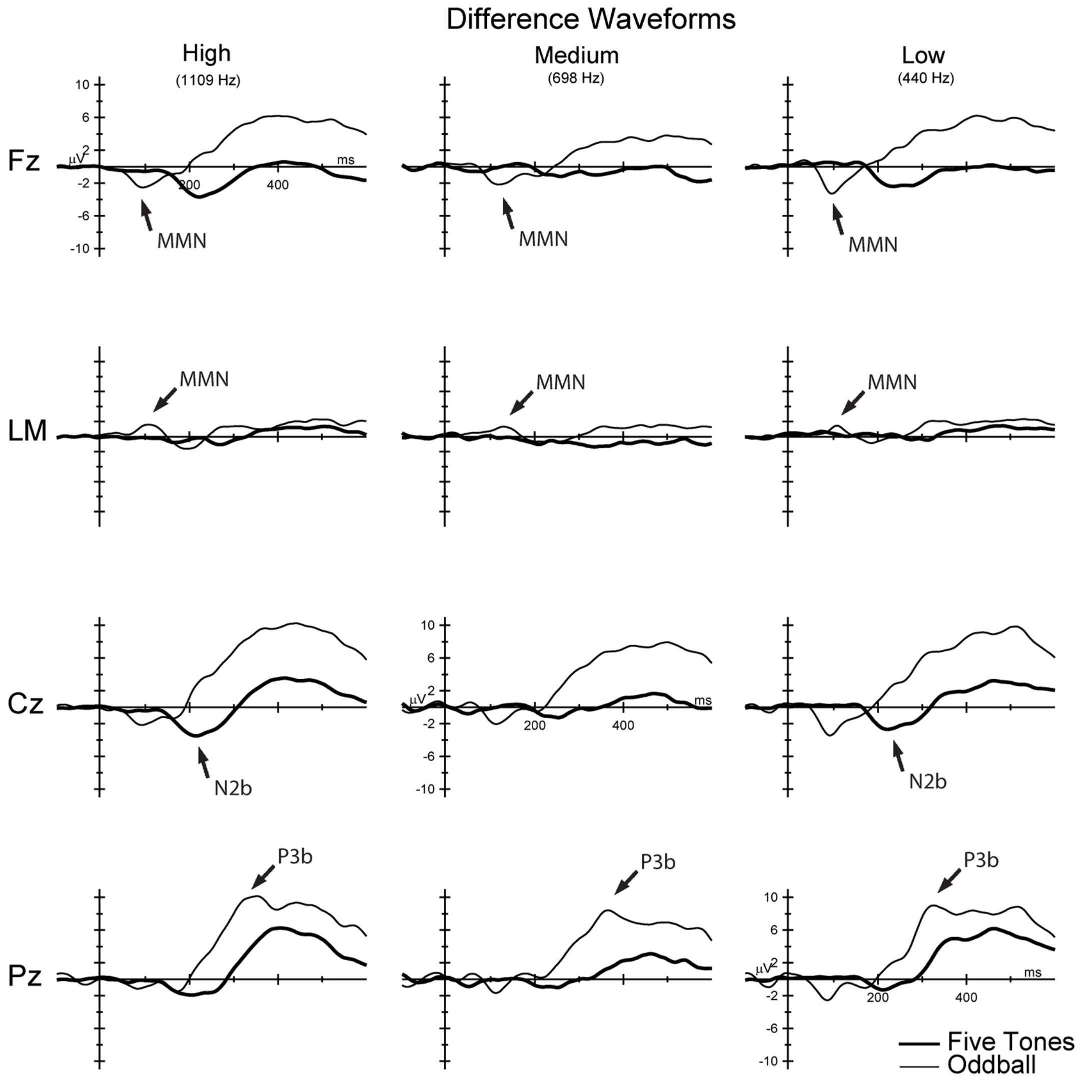

Figure 4. Difference Waveforms

Difference waveforms obtained by subtracting the ERPs elicited by the control stimulus (see Methods) from the ERPs elicited by the target are displayed for the midline electrodes, overlain by condition (Five-Tones thick solid line; Oddball thin solid line), at Fz (top row), LM (second row), Cz (third row), and Pz (bottom row), separately for the High (left column), Medium (middle column), and Low (right column) target tone conditions. Significantly elicited components are labeled with an arrow.

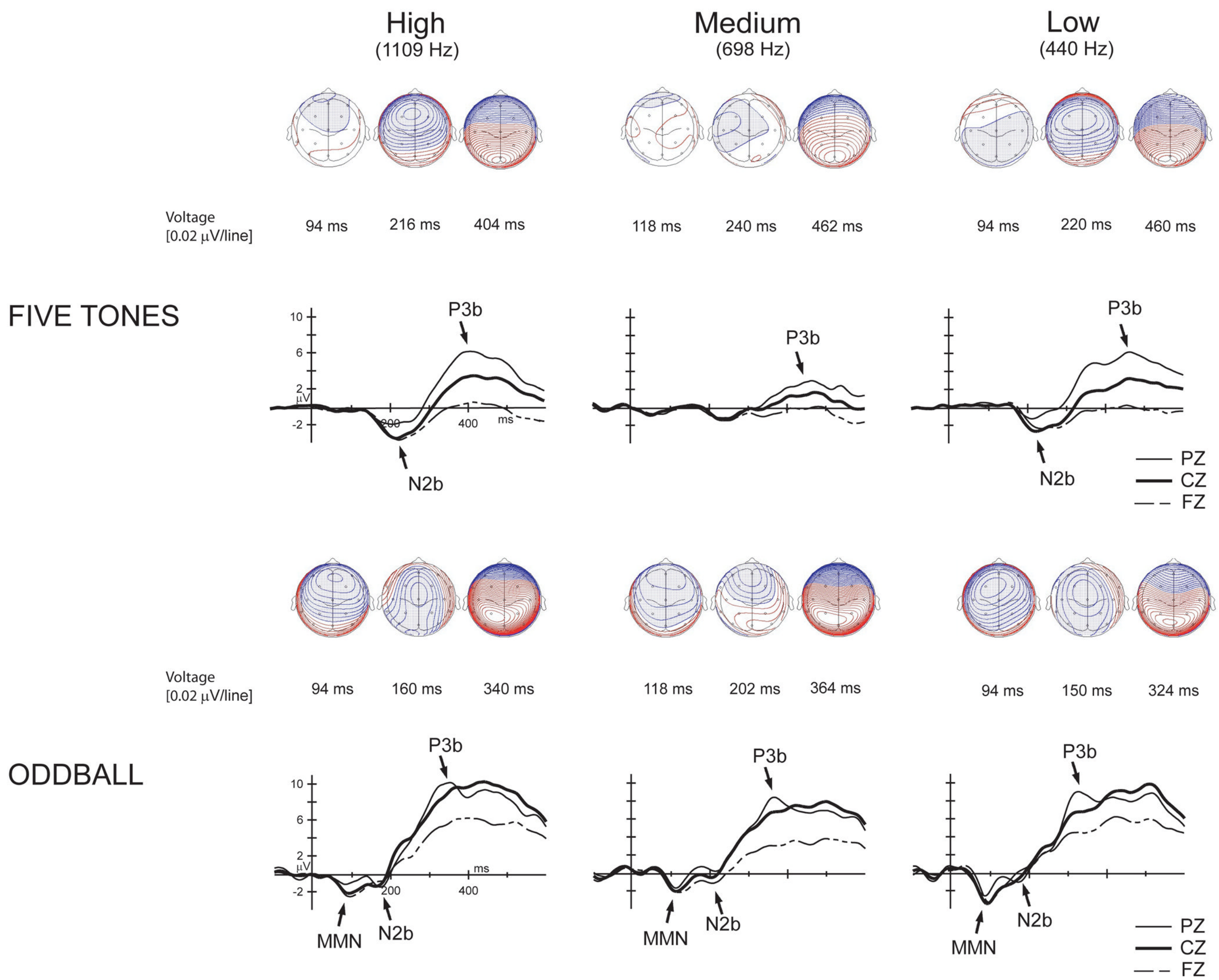

Figure 5. Difference Waveforms with voltage maps

Difference waveforms derived by subtracting the ERPs elicited by the non-target (control, see Methods) from the ERPs elicited by the target are displayed for the High (left column), Medium (middle column) and Low (right column) conditions separately, in the Five-Tones experiment (top) and the Control Oddball experiment (bottom). The scalp distribution of the voltages is displayed from the peak latency of the MMN, N2b, and P3b components in each respective condition. Significantly elicited components are labeled with an arrow.

Table 1

Behavioral Results (standard deviation in parentheses)

Experiment	Condition	Hit Rate	False Alarm Rate	Reaction Time (msec)
	High	0.90 (0.06)	0.01(.02)	401(38)
Five-Tones	**Medium**	0.42 (0.24)	0.14(.09)	504(55)
	Low	0.89 (0.07)	0.02(.02)	428(37)
	High	0.95 (0.06)	0	289(32)
Oddball	**Medium**	0.98 (0.02)	0	312(33)
	Low	0.97 (0.01)	0	303(15)

Table 2

ERP components with mean amplitudes and peak latencies (standard deviation in parentheses)

Experiment	Component	Electrode	Conditions (Target)	Amplitude (μV)	Latency (msec)
Five-Tones			**High**	−3.37 (2.9)	213 (15)
	N2b	Cz	**Medium**	−1.15 (2.7)	246 (14)
			Low	−2.57 (2.8)	217 (14)
			High	6.19 (2.1)	402 (16)
	P3b	Pz	**Medium**	3.02 (2.9)	462 (16)
			Low	6.05 (4.6)	456 (14)
Oddball			**High**	−2.36 (1.7)	96 (15)
		Fz	**Medium**	−2.05 (0.5)	123 (11)
			Low	−2.82 (0.8)	97 (7)
	MMN		**High**	1.46 (1.3)	110 (16)
		LM	**Medium**	1.18 (0.6)	135 (11)
			Low	1.13 (0.2)	105 (9)
			High	−1.24 (3.4)	160 (17)
	N2b	Cz	**Medium**	−0.36 (2.7)	204 (20)
			Low	−0.66 (3.1)	159 (14)
			High	9.96 (4.6)	349 (15)
	P3b	Pz	**Medium**	8.17 (6.1)	361 (14)
			Low	8.78 (3.6)	325 (15)