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Research article

# Changes in room acoustics elicit a Mismatch Negativity in the absence of overall interaural intensity differences

Johannes Daniel Frey[a,*], Mike Wendt[a,d], Andreas Löw[a], Stephan Möller[b], Udo Zölzer[c], Thomas Jacobsen[a]

[a] Experimental Psychology Unit, Helmut Schmidt University/University of the Federal Armed Forces Hamburg, Germany
[b] Central Electronics Services, Helmut Schmidt University/University of the Federal Armed Forces Hamburg, Germany
[c] Department of Signal Processing and Communications, Helmut Schmidt University/University of the Federal Armed Forces Hamburg, Germany
[d] Faculty of Human Sciences, Medical School Hamburg/University of Applied Sciences and Medical University, Germany

## HIGHLIGHTS

- An auditory pre-attentive detection of changing room acoustics is proposed.
- Violation of auditory regularities with respect to room acoustics resulted in a mismatch negativity.
- The mismatch negativity reflects pre-attentive detection of violations of auditory regularities.
- Violations of auditory regularities due to changed room acoustics are detected pre-attentively.
- Additional negative deflections follow after a mismatch negativity.

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ABSTRACT

Changes in room acoustics provide important clues about the environment of sound source-perceiver systems, for example, by indicating changes in the reflecting characteristics of surrounding objects. To study the detection of auditory irregularities brought about by a change in room acoustics, a passive oddball protocol with participants watching a movie was applied in this study. Acoustic stimuli were presented via headphones. Standards and deviants were created by modelling rooms of different sizes, keeping the values of the basic acoustic dimensions (e.g., frequency, duration, sound pressure, and sound source location) as constant as possible. In the first experiment, each standard and deviant stimulus consisted of sequences of three short sounds derived from sinusoidal tones, resulting in three onsets during each stimulus. Deviant stimuli elicited a Mismatch Negativity (MMN) as well as two additional negative deflections corresponding to the three onset peaks. In the second experiment, only one sound was used; the stimuli were otherwise identical to the ones used in the first experiment. Again, an MMN was observed, followed by an additional negative deflection. These results provide further support for the hypothesis of automatic detection of unattended changes in room acoustics, extending previous work by demonstrating the elicitation of an MMN by changes in room acoustics.



## 1. Introduction

A Mismatch Negativity (MMN) is a component of the event-related potential [1]. This component has consistently been observed when an infrequently presented sound, referred to as the *deviant*, occurs in a sequence of repetitions of a different sound, referred to as the *standard*, even when participants are attending to another (e.g., visual) source of stimulation and report no awareness of the occurrence of the deviant. MMN responses have been observed in connection with changes along basic auditory dimensions, such as pitch [2] or loudness [3], as well as more abstract irregularities [4]. An MMN reflects detection of a violation of an implicit prediction of impending auditory events, based on previously experienced regularity [1,5]. Given the particular sensitivity of the auditory system for perceiving distant events in the entire surrounding environment, such a monitoring mechanism seems particularly well suited for early identification of unpredicted, potentially important changes in the environment.

* Correspondence to: Holstenhofweg 85, D- 22043 Hamburg, Germany.
*E-mail address:* Johannes.Frey@hsu-hh.de (J.D. Frey).

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Although the behavioural relevance of the perception of room acoustics has long been established [6,7], research on automatic detection of room-acoustics-related changes in the environment has only recently begun. Specifically, Frey et al. [8] observed an MMN elicitation in an oddball protocol with a sequence of piano chords that differed in room acoustics. An MMN was reliably elicited, peaking about 180 ms after the onset of the first chord of the deviant chord sequence. This supports the notion of automatic detection of unattended changes in room acoustics.

Some peculiarities of the stimuli used in the study by Frey et al. [8] merit consideration. Most importantly, due to the manipulation of lateralized reflection properties, standards and deviants in that study were not symmetrical in terms of the overall sound intensity levels presented to the left and right ear. Given previous findings of MMN elicitation by interaural intensity differences [9], one cannot dismiss the possibility that the MMN observed by Frey et al. [8] was driven by this asymmetry. Interaural intensity differences can influence the perceived spatial location of sound sources. Within a certain range, they lead to perception of a sound as coming from a lateral source [9]. In addition, room acoustics also influence the reliability of judgements of sound source locations [10]. Moreover, assuming a difficulty of detecting room-acoustics-related changes with short, homogeneous stimuli, Frey et al. [8] repeatedly presented sequences made up of five different piano chords. An analysis of the time interval subsequent to the MMN revealed a second negative deflection in the ERP, about 260 ms after the onset of the second chord of the tone sequence.[1] Although it appears straightforward to assume multiple MMNs in this case, each reflecting the detection of a room-acoustics-related change for a particular chord, it is also conceivable that the two negative deflections reflect qualitatively different processes. Specifically, because alterations of room acoustics are characterized by a complex pattern of changes affecting various acoustic parameters, some minimal period of time may be necessary to detect the room-acoustical deviation from this pattern. Viewed from this perspective, it might be conjectured that only the second negative deflection indicated such a detection process, whereas the first MMN might have been elicited by low-level constituents of the pattern, that is, by one or more featural deviations which, in isolation, would not be indicative of a change in room acoustics. The subtle interaural intensity difference in the study by Frey et al. [8] is an obvious candidate for such a feature.

Based on these considerations, the current study sought additional evidence for the notion of automatic detection of unattended changes in room acoustics, controlling for differences in overall interaural intensity. To this end, changes in room acoustics which were left-right-symmetrical were simulated. Furthermore, we aimed to shed light on the role of multiple sounds in sequences by contrasting the presentation of three identical sounds (Experiment 1A) and a single uninterrupted sound (Experiment 1B) with the same overall duration. The assumption that multiple MMNs are elicited by the onsets of the constituent sounds of the deviant sequence predicts the occurrence of additional negative deflections only in the three-sound-sequence condition of Experiment 1A. Conversely, the assumption of consecutive detection of featural and room-acoustics-specific patterns of deviance also predicts a second negative deflection in the single-sound condition of Experiment 1B.

[1] Visual inspection revealed a third negative deflection, which was, however, not analysed further.

## 2. Material and methods

### 2.1. Participants

Sixteen volunteers participated in Experiment 1A (three female, mean age 24.6 years, age range 22–28, one left-handed). Sixteen additional volunteers participated in Experiment 1B (nine female, mean age 23.4 years, age range 21–26, one left-handed). Handedness was assessed using an inventory adopted from Oldfield [11].

All participants reported normal auditory and normal visual acuity and no neurological, psychiatric, or other medical conditions. The experiment was carried out in line with ethical guidelines, specifically, The Code of Ethics of the World Medical Association Declaration of Helsinki [12]. Informed written consent was obtained from all participants prior to the experimental session.

### 2.2. Materials

For Experiment 1A, a 500-ms-long sequence of three sinusoidal tones was generated. It consisted of 100 ms of tone, followed by 100 ms of silence, 100 ms of tone, 100 ms of silence, and 100 ms of tone. In addition, a constant interstimulus interval (ISI) of 100 ms was used between sequences (triplets). For Experiment 1B, a sinusoidal tone of 500 ms duration was generated, matching the tone triplet of Experiment 1A in overall duration. A constant ISI of 100 ms was also used in Experiment 1B.

The tones were then modified. First, the sinusoidal tones were converted into square waves in order to add spectral complexity. This addition of harmonics made the sounds more realistic than pure sinusoidal tones, thus adding external validity. Then, to generate different room acoustics, room simulations were used to reproduce the acoustics of a room. To this end, calculation of the stimulus parameters was based on a model of a fully symmetrical (i.e., spherical) room with no room modes.[2] The direct audio signals without room impressions were mapped to certain room acoustics. Specifically, the acoustical room properties of the room to be simulated were transformed into a room impulse response [13]. A fast convolution algorithm was used to generate the stimuli; the sounds presented to the participants were computed as the sum of the convolution (modelling the reverberation) and the original sound (square waves). The calculation (Matlab code) is provided in the Appendix.

For each experiment, four stimuli differing in reverberation times and convolution, corresponding to rooms of different sizes, were derived. The rooms were Alpha 1 (largest room), Alpha 3 (second largest room), Alpha 7 (third largest room), and Alpha 10 (smallest room). As a consequence of the manipulation between room sizes, the first two sound segments of the sequences (triplets) in Experiment 1A slightly differed in duration from the third. Because this difference was constant we considered it unlikely that it would affect the automatic detection of changes in room acoustics. At the end of the stimulus generation, a 5 ms fade in and fade out was added to all sounds in the sequences.

Finally, the total Root Mean Square (RMS) amplitude was equalized for all four stimuli. Time domain representations of the acoustic stimuli are presented in the Appendix.

[2] An idealized room was used that cannot be found in reality, but rooms resembling this room closely can be built. This perfect room without room modes was used to eliminate confounds due to resonances depending on the room and not the stimuli. This idealized room reflects all frequencies with equal strengh producing a linear spectrum without any peaks, resulting in an environment with reverberation with no resonances. The reflection properties of the simulated room resemble those of a diffuse environment like, for instance, a forest where the reflection from the trees is so diffuse that no frequencies are reflected stronger than others.