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Automatic detection of unattended changes in room acoustics

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HIGHLIGHTS

- An auditory automatic detection of changing room acoustics is proposed.
- A passive oddball protocol including auditory stimuli with deviating room acoustics was used.
- Violation of auditory regularities with respect to room acoustics resulted in a mismatch negativity.
- The mismatch negativity reflects automatic detection of violations of auditory regularities.
- Violation of auditory regularities due to changed room acoustics are detected automatically.

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ABSTRACT

Previous research has shown that the human auditory system continuously monitors its acoustic environment, detecting a variety of irregularities (e.g., deviance from prior stimulation regularity in pitch, loudness, duration, and (perceived) sound source location). Detection of irregularities can be inferred from a component of the event-related brain potential (ERP), referred to as the mismatch negativity (MMN), even in conditions in which participants are instructed to ignore the auditory stimulation. The current study extends previous findings by demonstrating that auditory irregularities brought about by a change in room acoustics elicit a MMN in a passive oddball protocol (acoustic stimuli with differing room acoustics, that were otherwise identical, were employed as standard and deviant stimuli), in which participants watched a fiction movie (silent with subtitles). While the majority of participants reported no awareness for any changes in the auditory stimulation, only one out of 14 participants reported to have become aware of changing room acoustics or sound source location. Together, these findings suggest automatic monitoring of room acoustics.

1. Introduction

The mismatch negativity (MMN), component of the human event-related brain potential (ERP), is a well-established measure for the investigation of pre-attentive auditory processing. The MMN is widely considered to reflect detection of violations of regularities extracted from the acoustic environment, that occurs even when the acoustic stimulation is not in the focus of attention [1]. In the simplest form, it is observed when a repeated sound (standard) is followed by a differing sound (deviant) at an unpredictable time. A mechanism that constantly monitors the acoustic environment and detects changes is likely to govern this process [2,3]. Different auditory dimensions have been shown to elicit MMN. So far, the four first-order auditory regularity violation dimensions that have been found to elicit a MMN are pitch [4–6], duration [7–9], loudness [10,11] and sound source location [12–14]. Higher-order auditory regularity violation dimensions eliciting a MMN have also been reported, for instance the omission of a tone in a recurrent pattern [15,16], or by speech stimuli violating abstract phonological rules followed by a sequence of standard stimuli [17].

Another auditory dimension that bears importance for perception and behavior, particularly in real life contexts, relates to sound properties arising from the reflecting characteristics of objects that make up the environment of the sound source-perceiver system. In a built-up environment as well as in a considerable portion of the natural environment, virtually all sound is affected by this phenomena, referred to as *room acoustics*. Previous research has shown that room acoustics impact both perceptual quality and behavioral performance. For instance, the reverberation time of a room influences the ability to localize the sounds, especially for the localization of continuous broadband noise [18]. Behavioral relevance of room acoustics has been demonstrated for (musical) sound production (i.e., professional piano players adapted their

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playing style to varying room acoustics [19]). Additionally, variations in room acoustics created by virtual rooms differing in size, influence the emotional valence of sounds [20]. Consequently a metric to assess the mental and neural mechanisms underlying the processing of room acoustics could improve research in this field.

In the current study, we investigated whether the human auditory system monitors the acoustic environment regarding this particular dimension. Given the sophisticated ability in detecting acoustic irregularities, on the one hand, and the perceptual–behavioral–emotional importance of room acoustics on the other, it seems likely that room acoustics-based sound changes are detected automatically (i.e., in the absence of a corresponding goal and possibly without awareness). Humans are not necessarily aware of these changes, which renders measuring brain waves a good means of observing reaction to changing room acoustics [21]. To examine this issue, we applied ERP recording in a passive oddball protocol involving standard and deviant stimuli that differed regarding a room-acoustical aspect.

2. Materials and methods

2.1. Participants

Fourteen volunteers participated in the experiment (five male, mean age 25.5 years, range 19–60, one left handed). Handedness was assessed using an inventory adopted from Oldfield [22]. All participants were native German speakers, reported normal auditory and normal visual acuity and no neurological, psychiatric, or other medical problems. The experiment was carried out in line with ethical guidelines, in particular The Code of Ethics of the World Medical Association (Declaration of Helsinki) [23]. Informed written consent was obtained from all participants prior to the experimental session.

2.2. Materials

By playing a sequence of five piano chords in two variations of a simulated room, two stimuli were constructed. A room acoustics software program (Odeon 11.00 Combined Demo Version; Odeon A/S, Kgs. Lyngby, Denmark) was used for auralisation. Odeon was developed for simulating the interior acoustics of buildings and uses the image-source method combined with ray tracing. An ambisonic recorded stimulus (derived from "Piano Over the rainbow Mic2 SHORT.wav" from the Odeon package) consisting of a sequence of five piano chords was used: F7 (2793 Hz), E7 (2637 Hz), D7 (2349 Hz), C7 (2093 Hz), & G6 (1567 Hz; base frequencies given in the parentheses). To avoid difficulties in perceiving room acoustics based on a single tone, we chose a stimulus of considerable complexity and duration. The chord sequence had an overall duration of 1040 ms, including 5 ms rise and 5 ms fall times. The onset times of the chords were at approximately 5 ms, 350 ms, 510 ms, 660 ms, and 837 ms after stimulus onset, with no silent periods between consecutive chords. For the auralisation a virtual room ("example.Par" from the Odeon package) was used. The simulated room's acoustic properties were altered to generate two auditory stimuli with different room acoustics but otherwise retained identical properties. The sound source was centered in front of the perceiver (point source; $(x, y, z) = (1, 0, 2)$; see Fig. 1A), and the connection between the sound source and the receiver formed an imagined line dividing the room into two symmetrical parts. The perceiver was seated in a central position with respect to the right and left walls (single point response receiver; $(x, y, z) = (20, 0, 5)$; see Fig. 1A). The surface area of the room was 1268.23 m^2, room temperature 20 °C, relative humidity 50%. The reflective properties of walls were altered to generate two stimuli with different room acoustics (Fig. 1A). For one stimulus ("right") a 90% absorbing material (equally absorbing all frequencies) was applied to the walls to the right of the receiver and for all other walls a 10% absorbing material (equally absorbing all frequencies) was used. This room setup produced the impression that the room was open to the right. For the second stimulus ("left") a 90% absorbing material was applied to the walls to the left of the receiver and all other walls were covered with 10% absorbing material, giving the impression that the room was open to the left, creating a fully symmetric counterpart.[1] As a consequence, the total Root Mean Square (RMS) of "left" and "right" was the same. Remaining intensity differences due to stochastic aspects of the re-synthesis procedure were equalized using Adobe Audition CS5.5 Demo Version (Adobe Systems GmbH, München, Germany); mean RMS amplitude for "right" (left channel: −18.33 dB; right channel: −21.91 dB) and "left" (left channel: −22.07 dB; right channel: −18.31 dB). Different mean RMS amplitudes between the channels were essential in order to maintain the different acoustic properties of the two rooms (see Fig. 1C). As a consequence, there are intensity differences between the two channels. The frequency spectrum (see Fig. 1B) reveals that channel right of stimulus "left" is not identical as channel left of stimulus "right". Software simulating acoustics cannot make perfect calculations therefore each auralisation does differ slightly. The acoustic stimuli can be found at: http://www.hsu-hh.de/allgpsychologie/index_Ld3q1e6qG8cZO048.html (Fig. 2).

Deviant stimuli could be actively discriminated from standard stimuli with high accuracy.[2] To test participants' awareness of the deviant stimuli in the passive oddball protocol the fourteen participants of the EEG experiment were interviewed about their subjective impression regarding the auditory stimuli (approximately 5 min after completing the EEG experiment). Ten participants reported that they did not notice any changes to the auditory stimuli, two participants said they felt that the rhythm was sometimes different, one participant reported differences in the sound's source location and only one participant had the feeling that something with the room's acoustics changed, but could not specify this observation further.

2.3. Experimental design and procedure

The participants were seated in an electrically and acoustically shielded experimental chamber (Industrial Acoustics Company GmbH, Niederkrüchten, Germany). 2000 acoustic stimuli were presented binaurally at approximately 52 dB SPL[3] (artificial head HMS

[1] The following Odeon configuration was used: (1) Room setup: Impulse Response Length 16,000 ms, Number of late rays 20,000, Max. reflection order 2000, Impulse response resolution 3.0 ms, Transition Order 2, Number of early scatter rays 100, Angular absorption "Soft materials only", Surface scattering "Actual", Oblique Lambert, Reflection based scatter "enabled", Key diffraction frequency 707 Hz, Interior margin 0.10 m, Scatter coefficients > 0.50 handled as uniform scatter. (2) Auralisation setup: Apply dither and noise shaping, Wave result file 16 bit PCM, Create binaural impulse response file, HRFT "Subject_021-Res10deg_M3,0_SRate44100_Apass0,50_Astop40,00_BOvrLap100%_PPrHRTF256", Headphone "Sennheiser HD250Linearll.44100.ee.hph, DC filter, Overall Recording level 40 dB, Phase approximation "phase shift at surfaces/filter phase, A(stop) 40,00 dB, A(pass) 0,50 dB, Band overlap 100%, Sample rate 44100 Hz, Encoding "1. Order ambisonics".

[2] To assess discriminability of the two stimuli, another group of ten participants (six male, mean age 28.9 years, range 20–50) who reported normal auditory acuity were asked to detect the one deviant stimulus in a sequence of 10 stimuli. The "right" stimulus was interspersed in a sequence of nine presentations of the "left" stimuli and vice versa. All ten participants completed 20 of these sequences with one deviant at a random position in each of the sequences (1800 standard; 200 deviant). In total, 185 deviants (92.5%) were detected with 4 false alarms (0.22%).

[3] Configuration: equalization (LIN), synchronization (44.1 kHz), tool (SPL), without torso.