



Research paper

Brief bursts of infrasound may improve cognitive function – An fMRI study



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ABSTRACT

At present, infrasound (sound frequency < 20 Hz; IS) is being controversially discussed as a potential mediator of several adverse bodily as well as psychological effects. However, it remains unclear, if and in what way IS influences cognition. Here, we conducted an fMRI experiment, in which 13 healthy participants were exposed to IS, while cognitive performance was assessed in an n-back working memory paradigm. During the task, short sinusoidal tone bursts of 12 Hz were administered monaurally with sound pressure levels that had been determined individually in a categorical loudness scaling session prior to the fMRI experiment. We found that task execution was associated with a significant activation of the prefrontal and the parietal cortex, as well as the striatum and the cerebellum, indicating the recruitment of a cognitive control network. Reverse contrast analysis (n-back with tone vs. n-back without tone) revealed a significant activation of the bilateral primary auditory cortex (Brodmann areas 41, 42). Surprisingly, we also found a strong, yet non-significant trend for an improvement of task performance during IS exposure. There was no correlation between performance and brain activity measures in tone and no-tone condition with sum scores of depression-, anxiety-, and personality factor assessment scales (BDI, STAI-X1/X2, BFI-S). Although exerting a pronounced effect on cortical brain activity, we obtained no evidence for an impairment of cognition due to brief bursts of IS. On the contrary, potential improvement of working memory function introduces an entirely new aspect to the debate on IS-related effects.

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1. Introduction

The term ‘infrasound’ (IS) applies to sounds in the very low-frequency range (1 Hz < frequency < 20 Hz), which are ubiquitous in our environment. While IS can be a by-product of natural events (such as the flow of rivers or avalanches), it is emanating in abundance from man-made sources such as jet engines, road traffic and wind turbines. Exposure to IS is frequently reported to be annoying, irritating or disturbing (Kaczmarek and Łuczak, 2007) and over the past decades, a number of adverse health effects have been attributed to IS, ranging from psychological and behavioural alterations to respiratory and cardiovascular disorders (Huang

et al., 2003; Ferreira et al., 2006; Pei et al., 2007). More recently, the debate on whether IS should be considered hazardous to human health reached a broader audience, as increasing numbers of people living in close proximity to wind parks reported several potentially IS-related symptoms, including cognitive impairments such as difficulties in concentration and memory loss (Punch and James, 2014). These reports have even motivated the description of a novel clinical condition, the so called “Wind Turbine Syndrome” (WTS) (Pierpont, 2009), in which symptoms are explained as the consequence of an overexposure to low- and very low-frequency noise produced by the turbines. There's an ongoing debate, whether such symptoms can be explained as the result of a communicated nocebo-effect (i.e. triggered by high expectations and shared beliefs about the harmfulness of low-frequency sounds), or emerge in a bottom-up fashion, in the sense that IS precipitates more global changes of nervous function due to its

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action via auditory (or even somatosensory) pathways. The cases presented above clearly illustrate that the identification of potentially hazardous health effects of IS is a relevant public health issue and further research is required in order to evaluate, whether protection standards against low frequency noise need to be established (Duck, 2007).

Traditionally, IS frequencies are considered to be too low for the sound to be audible by humans (humans are said to have a hearing range of about 20 Hz–20,000 Hz). Therefore, it has been a widely held view that such frequencies are unable to influence inner ear function. Consequently, neural processes upstream in the central nervous system that could lead to the emergence of adverse psychological effects should also remain unaffected. However, it has been demonstrated in a number of studies that this view fails to recognize the complex physiology that underlies the ears' response to IS (Salt and Hullar, 2010). For example, it has been shown repeatedly that given a high enough sound pressure level, IS can very well be perceived (Robinson and Dadson, 1956; Corso, 1958; Whittle et al., 1972; Yeowart and Evans, 1974; Landstroem et al., 1983; Verzini et al., 1999; Schust, 2004; Møller and Pedersen, 2004). In addition, 2 studies revealed IS-induced changes of the distortion product otoacoustic emissions (DPOAEs) in animals (Marquardt et al., 2007), as well as in normally hearing human participants (Hensel et al., 2007). Since the DPOAE response is generally used as an objective indicator to examine cochlear amplification mediated by the outer hair cells, these findings clearly speak against the traditional view that IS has no influence on inner ear function. A functional magnetic resonance imaging (fMRI) study also showed that monaural acoustical stimulation with tone bursts of 12 Hz leads to a bilateral activation of the primary auditory cortex (Brodmann area 41/42) for sound pressure levels of 110 and 120 dB, while no significant activation during stimulation with 90 dB was observed (Dommes et al., 2009).

Since IS has been associated with cognitive impairments and a growing number of studies linked IS exposure to changes of inner ear and brain function, we set out to address the question, whether IS also affects cognitive processing. We hypothesized that IS would exert a negative influence on performance in an n-back working memory task and that this impairment would be reflected in changes of cortical brain activity, measured via fMRI. We also expected participants, scoring higher on scales in which depression, anxiety or neuroticism was assessed, to be more prone to experience detrimental performance or brain activation effects.

2. Experimental procedures

2.1. Participants

Thirteen healthy participants (7 female) with a mean age of 23.7 years ($SD = 2.9$) took part in the study on the basis of informed consent. The study was conducted according to the Declaration of Helsinki, with approval of the local ethics committee. All participants had normal or corrected-to-normal vision and were otologically normal (as assessed by means of the ISO 389-9:2009 questionnaire filled out by all participants). No participant had a history of neurological, major medical, or psychiatric disorder. All participants were right-handed as assessed by the Edinburgh handedness questionnaire (Oldfield, 1971).

2.2. Procedure

Participants took part in two separate sessions, one consisting of a loudness scaling by means of categories and one of tone presentation under fMRI conditions. Categorical loudness scaling is a standardized method (ISO 16832:2006), in which the perceived

loudness of stimuli over the whole dynamic range of the auditory system is assessed. Here, participants are asked to rate the loudness of given stimuli using a scale with named categories such as soft, medium, loud, etc. For the present study, we selected a pure sinusoidal stimulus with a frequency of 12 Hz. Sound pressure levels were determined individually from derived loudness functions (Brand and Hohmann, 2001), in order to generate a subjective hearing impression of the test stimulus (later to be used under fMRI conditions) that was equally loud across participants. The average sound pressure level determined in those loudness scaling sessions was 115 dB with an applied maximum of 124 dB and a minimum of 111 dB across participants, corresponding to a stimulus of “medium” loudness. Directly after the scan, all 13 participants were asked, if IS stimulation had been perceived and if the tone could clearly be distinguished from scanner noise. Participants were also asked, whether stimulation had an effect on task performance.

2.3. Stimulus paradigm

Sound signals were generated by a DAC-device of a 24 bit soundcard within a personal computer, amplified or attenuated and fed to a modified loudspeaker system outside of the MRI room. The loudspeaker system was attached to a polyethylene tube (length 8 m, inner diameter 14 mm) (Kuehler et al., 2015) leading to the participants' right ear (Fig. 1). In order to avoid audible transients, the 12 Hz pure tone used for stimulation was faded in and out with a $\cos^2$ on- and offset ramp of 250 ms (3 cycles) and had a total duration of 3000 ms (Fig. 2A). In order to minimize the interference of scanner noise, a regular M™ EAR™ One Touch Earplug (Noise Reduction Rating (NRR): 33 dB) was used for the left ear. In addition, both ears were covered with a Silverline 140858 ear defender (NRR: 22 dB). An optical, metal-free microphone (Sennheiser MO-2000) was coupled to the sound path by means of a T-fitting 20 cm downstream of the ear, in order to enable online monitoring of sound pressure levels. Using this microphone, we also verified that no higher harmonics were generated by the speaker or the transmission elements. Participants were instructed to listen attentively and to avoid movements of their bodies (Scholz et al., 2009).

2.4. N-back task

Cognitive performance was assessed in a so-called spatial n-back working memory task. In each n-back block, a sequence of 10 black dots appeared at varying locations on a 4 by 4 grid. By pressing one of two buttons (index or middle finger of the right hand) participants indicated, whether or not each dot appeared at the same position as the dot presented three steps earlier in the sequence (3-back) (Fig. 2B). Dots were displayed for 500 ms at random locations on the grid, with the constraint of not appearing at the same location in 2 consecutive steps. The inter-stimulus interval (ISI) between two blocks (each lasting 5000 ms) was 2750 ms (Fig. 3). During fMRI acquisition, a fixation period of 20 s was inserted after 10 blocks. Overall, participants took part in two separate fMRI runs with 10 blocks of n-back performance each. During each run, half of the blocks were accompanied by the presentation of the IS-stimulus. Over the course of each block, the stimulus was looped, therefore accounting for an overall stimulus duration of 4250 ms per block (throughout the remaining 750 ms the stimulus was ramped on and off). Apart from the presence of absence of tone administration, the blocks were identical in order to allow direct comparison, but presented at random.

2.5. Questionnaires

We used the Beck Depression Inventory (BDI) (Beck et al., 1996)

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