Neuroanatomical substrate of noise sensitivity

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ABSTRACT

Recent functional studies suggest that noise sensitivity, a trait describing attitudes towards noise and predicting noise annoyance, is associated with altered processing in the central auditory system. In the present work, we examined whether noise sensitivity could be related to the structural anatomy of auditory and limbic brain areas. Anatomical MR brain images of 80 subjects were parcellated with FreeSurfer to measure grey matter volume, cortical thickness, cortical area and folding index of anatomical structures in the temporal lobe and insular cortex. The grey matter volume of amygdala and hippocampus was measured as well. According to our findings, noise sensitivity is associated with the grey matter volume in the selected structures. Among those, we propose and discuss particular areas, previously linked to auditory perceptual, emotional and interoceptive processing, in which larger grey matter volume seems to be related to higher noise sensitivity.

Introduction

Noise, described as an any unwanted sound irrespective to its physical properties, can adversely affect our well-being. A large body of research links noise to general disturbance, sleep problems, cognitive impairments and cardiovascular diseases (for reviews, Basner et al., 2014; Stansfeld and Matheson, 2003). Nevertheless, susceptibility to the negative health effects of noise differs among people. One of the indicators of the vulnerability to the environmental noise is *noise sensitivity*. Noise sensitivity describes a stable individual trait that determines a general attitude towards noise (Stansfeld, 1992). According to the definition of Job (1999), it refers to physiological and psychological (also including attitudinal) internal states of any individual, which determines reactivity to noise. Noise sensitivity predicts noise annoyance (Stansfeld, 1992; van Kamp et al., 2004), and it influences one's evaluation of the soundscape's pleasantness (Lindborg and Friberg, 2016). Moreover, noise sensitivity moderates one's daily behaviour; for instance, noise-sensitive individuals

rarely have music in the background (Kliuchko et al., 2015) and often use hearing protection at work (Heinonen-Guzejev et al., 2011).

Noise sensitivity has not been linked to the acuity of peripheral hearing, intensity discrimination, or auditory reaction time (Ellermeier et al., 2001; Heinonen-Guzejev et al., 2011; Stansfeld et al., 1985). However, it is shown to be related to the mechanisms of the central sound processing (Kliuchko et al., 2016; Shepherd et al., 2016). Noise sensitivity is also correlated with annoyance induced by noise (Heinonen-Guzejev, 2008), which suggests that noise-sensitive individuals develop affective reaction towards noise easier than noise-resistant individuals. Some authors suggested that noise sensitivity is a part of a general predisposition of an individual to experiencing negative emotions towards events, sensations and self (Watson and Clarck, 1984) as well as exhibiting increased responses to stress and discomfort (Persson et al., 2007; Weinstein, 1978). In the present study, we aimed at investigating whether morphological variations in the structure of auditory and non-auditory brain areas dedicated to sensory-emotional processing

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and evaluation of auditory information could be related to noise sensitivity.

Recent electrophysiological studies have associated noise sensitivity with neural deficits in central auditory function, advocating for a perceptual/sensory component to noise sensitivity. As such, highly noise-sensitive individuals were found to exhibit altered sensory gating (Shepherd et al., 2016) and pre-attentive discrimination of sound noisiness (Kliuchko et al., 2016). These functional changes could be paralleled by anatomical differences in the central auditory structures. The relation between function and structure of auditory areas is found, for instance, in autistic patients. They are reported to have reduced volume of the planum temporale (Rojas et al., 2002), which is involved with segregation and matching spectrotemporal auditory information (Griffiths and Warren, 2002). Poor abilities in segregating relevant acoustic signals, in turn, are related to the sound intolerance that is exhibited in autistic patients (Lodhia et al., 2014). If noise sensitivity is related to deficits in the auditory processing, we could expect a negative relationship between noise sensitivity and the size of auditory cortical areas. On the other hand, their enlargement could mean an involvement of wider areas into sound processing that could result in hypersensitivity to sounds.

However, auditory areas of the temporal lobe are not the only structures that contribute to the processing of the auditory signal. Subcortical amygdala and hippocampus are responsive to physical features and regularity of sensory input. For instance, animal studies (Bordi and LeDoux, 1992) and human functional magnetic resonance imaging (fMRI) (Kumar et al., 2012) showed that amygdala encodes acoustical cues that are relevant to the evaluation of emotional valence. A sustained amygdala activation can be evoked by unpredictable auditory stimulation, and this activation is coupled with anxiety-like behaviours (Herry et al., 2007). The hippocampus is also involved on auditory information processing and contributes to sensory gating, which is an inhibition of irrelevant, repetitive sensory input (Cromwell et al., 2008). Moreover, the amygdala-hippocampal complex displays a unidirectional coupling during processing of emotionally important stimuli, so that amygdala detects a stimulus' salience and then influences dynamics of the hippocampal response to it (Zheng et al., 2017). In turn, hippocampus-dependent memory representations of stimulus emotional significance can influence amygdalar function (Phelps, 2004).

Both the hippocampus and amygdala have rich connections with auditory areas of the brain. Amygdala receives inputs from the auditory cortex and less processed information directly from the thalamus. Through its connections to the inferior colliculus, the amygdala may potentially influence the processing of an auditory stimulus even before it reaches the cortex (Marsh et al., 2002). The hippocampus, in turn, does not have direct connections with the primary and secondary auditory cortical areas (Mohedano-Moriano et al., 2007), but it is largely interconnected with auditory associative areas either directly or via pathways coming through the amygdala, insula, and other cortical areas, such as the temporal pole (Pascual et al., 2015). The hippocampus responds to sounds or the sound deprivation (e.g., in hearing loss) with the neuroplastic changes in its functional and structural organization (Kraus and Canlon, 2012). Moreover, the volume of amygdala and hippocampus is known to decrease in chronic stress (Abdalla and Geha, 2017), and small hippocampus is predictive for pathological stress responses (Gilbertson et al., 2002). In relation to noise sensitivity, an increase and decrease in amygdalar and hippocampal volumes could be expected alike. A larger volume of these structures could indicate increased activation of amygdala during sound processing, from which an enlargement of both amygdala and hippocampus could follow, as they are functionally tight. In turn, a decrease in volume of hippocampus and amygdala could result from emotional stress noise-sensitive people experience in response to noises.

In addition to the auditory cortex, amygdala, and hippocampus, an important role in stimulus evaluation is played by insula. A recent study found that the insula is related to symptoms of a distress caused by tinnitus but not to the characteristics of tinnitus itself, such as its loudness (Leaver et al., 2012). Further, in misophonia (an affective disorder characterized by negative emotions towards specific sounds, such as chewing or swallowing) the activation of bilateral anterior insula increased parallelly with higher subjective misophonic distress caused by a triggering sound (Kumar et al., 2017). Other studies propose that anterior insula is involved in anticipation of aversive bodily states and negative emotions (Phelps et al., 2001). Moreover, insula, along with the amygdala and the hippocampus, can have an influence on autonomic functions. Shepherd et al. (2016) observed differences in the dynamics of heart rate in response to emotional stimuli and heart rate variability between noise-sensitive and noise-resistant groups. Changes in heart rate serve as indices of noise sensitivity affecting integration between central and autonomic nervous systems (Thayer and Lane, 2000). Hence, we expected that noise sensitivity could be related to the structure of the insular cortex that is involved in regulating autonomic functions and plays a major role in the interoceptive feeling. As the insular cortex and, specifically, its anterior part was found enlarged in relation to distress caused by sound sensitivities, such as tinnitus and misophonia (Leaver et al., 2012), we could expect the same pattern of structural change to occur in relation to noise sensitivity.

In this study, we measured grey matter volume and morphology (cortical area, cortical thickness and cortical folding) in selected regions of interest from both cerebral hemispheres, namely auditory regions, hippocampus, amygdala, and insula, using FreeSurfer package for an automatic parcellation and labelling of cortical and subcortical structures (Dale et al., 1999; Fischl et al., 1999). These measures were used to explore whether noise sensitivity is related to changes in the brain morphology and what the direction of that relationship is.

Methods

Participants

The experimental procedure for this study was included in the research protocol "Tunteet" (Emotions), which was approved by the Coordinating Ethics Committee of the Hospital District of Helsinki and Uusimaa. All experiments were conducted in agreement with the ethical principles of Declaration of Helsinki. Subjects were recruited through email lists of the University of Helsinki. The inclusion criteria consisted of MRI safety considerations as well as the absence of hearing, neurological and psychiatric problems. All participants gave their written consent to participate in the study prior to the experiment. They were compensated for their time spent in the laboratory, traveling and filling questionnaires online by culture vouchers.

From the "Tunteet" dataset we selected those participants that underwent anatomical MR scanning and whose images were successfully parcellated with FreeSurfer (N = 121). Two of them were excluded from the analysis due to brain abnormalities detected by a neuroradiologist. Thirty-eight subjects decided not to complete online questionnaires (see the section below), and thus their data could not be studied. Additionally, one participant was an outlier with more than three standard deviations lower NSS than the mean and was excluded from the analysis. The final set consisted thus of 80 participants: 39 males and 41 females with an age range from 19 to 52 years (M_{age} = 28.8; SD = 7.8).

Questionnaires

Noise sensitivity was assessed using the Weinstein's Noise Sensitivity Scale (Weinstein, 1978). The questionnaire consists of 21 statements to rank on a 6-point Likert scale ranging from "agree strongly" to "disagree strongly". Fourteen items were reverse-scored. The total sum represents noise sensitivity score (NSS), and a higher score corresponds to higher sensitivity. The questionnaire was distributed as a part of an online Helsinki Inventory of Music and Affective Behaviors (HIMAB, Burunat et al., 2017, 2015; Gold et al., 2013; Kliuchko, 2017). The inventory completion was left to participants' choice depending on how much time they were willing to dedicate to the Tunteet protocol.