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Alterations to the attention system in adults with tinnitus are modality specific

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ABSTRACT

Generation and persistence of tinnitus following hearing loss may be due to aberrant engagement of attention. Here, functional MRI was used to determine differences in auditory and visual attention processing in adults with tinnitus and hearing loss compared to two age-matched control groups, one with matched hearing loss and the other with normal hearing thresholds. Attentional processing was investigated using a short-term memory task with varying loads, employing unfamiliar Korean letters in the visual condition and non-speech sounds in the auditory condition. We found similar behavioral response across the three groups for both modalities and tasks. For the auditory modality, the response of the attention network was suppressed in the tinnitus group compared to the control groups for both task loads, with the effect being more pronounced at high load. In contrast, in the visual modality, the tinnitus group exhibited greater response of the attention network, regardless of memory load, compared to the control groups. The results increase our understanding of the neural mechanisms of tinnitus and suggest that interventions that manipulate attention, especially in the visual domain, should be further investigated.

1. Introduction

Tinnitus is the conscious perception of sound in the absence of an external source (Adjiaman et al., 2009). The sound perceived may be different for every tinnitus sufferer, but is often described as ringing, buzzing, hissing, whistling, humming, or cricket-like (Stouffer and Tyler, 1990). Four to 15% of the general population and twenty percent of adults over age 50 have tinnitus (Møller, 2007). 30–40% of persons with hearing loss experience tinnitus, whereas 90% of tinnitus

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sufferers report some form of hearing loss (Davis and Rafaie, 2000). Tinnitus and hearing loss can both significantly reduce the quality of life of sufferers when they are severe or profound (Dalton et al., 2003; Sindhusake et al., 2004). In cases with extremely severe tinnitus, anxiety, depression, and even suicide can occur (Bartels et al., 2008). Currently, there is no cure for tinnitus, although therapies exist to manage an individual's reaction to it (Henry et al., 2014). One major obstacle to developing new and better tinnitus therapies is an incomplete understanding of neural bases of tinnitus.

Recently, the attention network has become a focus of study in tinnitus research (Roberts et al., 2013). Attention is ubiquitous, yet elusive, in that it is difficult to measure or quantify (Fritz et al., 2007). Attention is part of all deliberate tasks engaged in a top-down fashion (Johnson and Zatorre, 2005; Kastner and Pinsk, 2004) and is also based on bottom-up salience of a stimulus (Kayser et al., 2005). Tinnitus, then, may be caused by aberrant engagement of top-down attention, or abnormal bottom-up attention, wherein internal noise gains salience when the external environment is quiet. It may also be an interaction of the two processes, as argued in (Roberts et al., 2013), and further may implicate both an initial capture of attention and a later lack of dis-engagement in a timely fashion (Heeren et al., 2014). Based on the 'effortfulness' hypothesis of (Rabbitt, 1968), both hearing impairment and tinnitus may deplete attention resources thus leaving fewer attention resources for completing cognitive tasks. In the case of tinnitus, the reallocation may be to the percept itself, causing interference with other attention-demanding activities, whereas in the case of hearing loss alone, the noisy input channel may cause additional resources to be diverted to parse the incoming sounds.

The impact of tinnitus on concentration has been noted in several behavioral studies (Araneda et al., 2015; Hallam et al., 2004; Heeren et al., 2014; Rossiter et al., 2006; Stevens et al., 2007), and questionnaires assessing tinnitus-related handicap routinely ask patients about such concentration difficulties (e.g., Meikle et al., 2011; Newman et al., 1996; Tyler et al., 2014). The impact of hearing loss on attention-demanding tasks has been even more extensively studied, primarily in the context of age-related hearing loss (Best et al., 2009; Craik, 2007; Passow et al., 2012; Passow et al., 2014).

Neuroimaging studies of tinnitus in humans have focused on the role of cortical areas and have linked the tinnitus percept to brain areas more commonly associated with processing of attention and short-term memory or other extra-auditory functions (e.g., Andersson et al., 2000; Burton et al., 2012; Giraud et al., 1999; Mirz et al., 2000b; Schmidt et al., 2013). Although attention may be modality-specific, the cingulo-frontal-parietal network can be said to participate in amodal attention processing related to executive control (Petersen and Posner, 2012). In a PET study of gaze-evoked tinnitus, (Giraud et al., 1999) found the conscious perception of tinnitus to be associated with activation in temporo-parietal regions, which are also known to play a role in working memory. In a similar study (Lockwood et al., 2001), patients with gaze-evoked tinnitus had plastic changes in multiple neural systems, including frontal eye fields and regions in the frontal, parietal and temporal cortices. Mirz et al. (Mirz et al., 2000a; Mirz et al., 2000c) concluded that the perception of tinnitus may involve the dorsolateral prefrontal cortex (which plays a role in attention), the limbic system, and the secondary auditory cortex. Animal studies (see the review by (Roberts et al., 2013)) have also noted the engagement of the basal forebrain and the cholinergic system (useful in mediating attention) in animals with tinnitus.

Although tinnitus usually co-occurs with hearing loss, neuroimaging studies of tinnitus, including the ones listed previously, have largely ignored the role of hearing loss. In a previous fMRI (Husain et al., 2011), we studied a group of patients with tinnitus and hearing loss (TIN), patients with hearing loss only (HL) and controls with normal hearing thresholds (NH) while they performed an auditory discrimination task. Differences in the engagement of the attention and short-term memory network (henceforth shortened to ASM) in the auditory modality, which comprises areas in the frontal cortex, inferior parietal cortex, dorsomedial frontal gyrus / anterior cingulate, and superior temporal gyrus, were noted during the task. The HL group engaged the superior temporal, superior frontal, inferior parietal and anterior cingulate cortices significantly more than the NH group. In the TIN group, there was less widespread response of the superior and middle frontal gyri as well as the inferior parietal cortices compared to the control groups. NH subjects exhibited marginal anterior cingulate cortical response and marginal responses in the frontal and parietal cortices compared to TIN and HL. These results suggest that differential engagement of the ASM network may be a key difference in the neural mechanisms underlying hearing loss alone and hearing loss with tinnitus.

In this study, we investigated the differences (if any) between NH, TIN, and HL groups in the functionality of the ASM network under two different memory loads (high and low) and in auditory and visual modalities. An assumption of the study is the substantial involvement of the attention network in mediating a short-term memory task. Previous work, primarily using visual or verbal stimuli, has made this connection (Fougnie, 2008). In this context, non-unitary attention can be differentiated into a peripheral/perceptual system (bottom-up) and a central system (top-down), with the former engaged in orienting toward relevant stimuli and the latter used for executive function. A perceptual model of attention would argue for interference caused by tinnitus primarily in the auditory domain. The work of Sorqvist and colleagues (Sorqvist, 2010; Sorqvist et al., 2012) supports a unified model of attention wherein capacity of central mechanisms (as manifested in a short-term memory task) affects early sensory processing in any modality. This would suggest that tinnitus would affect both auditory and visual modalities. Here, we consider two competing hypotheses: one, both the auditory and visual tasks will show significant differences between the three groups, with distinct measurable differences between the tinnitus and the control groups; and two, only the auditory but not the visual modality will show significant differences between the tinnitus patient group and control groups. This second case could be driven in several ways. First, the effect of tinnitus could be restricted to the auditory attention network. Alternatively, because we recruited individuals with mild tinnitus, it is also possible