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Altered top-down cognitive control and auditory processing in tinnitus: evidences from auditory and visual spatial stroop.

Araneda R, De Volder AG, Deggouj N, Philippot P, Heeren A, Lacroix E, Decat M, Rombaux P, Renier L.

Institute of Neuroscience (IoNS), Université catholique de Louvain, Avenue Hippocrate 54, UCL-B1.5409, B-1200 Brussels, Belgium. Corresponding author : De Volder AG.

Abstract

Purpose: Tinnitus is the perception of a sound in the absence of external stimulus. Currently, the pathophysiology of tinnitus is not fully understood, but recent studies indicate that alterations in the brain involve non-auditory areas, including the prefrontal cortex. Here, we hypothesize that these brain alterations affect top-down cognitive control mechanisms that play a role in the regulation of sensations, emotions and attention resources.

Methods: The efficiency of the executive control as well as simple reaction speed and processing speed were evaluated in tinnitus participants (TP) and matched control subjects (CS) in both the auditory and the visual modalities using a spatial Stroop paradigm.

Results: TP were slower and less accurate than CS during both the auditory and the visual spatial Stroop tasks, while simple reaction speed and stimulus processing speed were affected in TP in the auditory modality only.

Conclusions: Tinnitus is associated both with modality-specific deficits along the auditory processing system and an impairment of cognitive control mechanisms that are involved both in vision and audition (i.e. that are supra-modal). We postulate that this deficit in the top down cognitive control is a key-factor in the development and maintenance of tinnitus and may also explain some of the cognitive difficulties reported by tinnitus sufferers.

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Supplement:

Tinnitus affects 5-15% of the population in western countries and its prevalence increases with age and with exposure to noise. Tinnitus is the perception of sound in the absence of external stimulation. It is often perceived as a ringing, hissing, whistling or buzzing sound. Unfortunately, at present there is no definite cure to tinnitus, whereas it may severely impair the quality of life. Most researchers agree that tinnitus is triggered by peripheral mechanisms (e.g. damage to the inner ear) and involves the central nervous system when it becomes chronic. On the one hand, there is an indication that alterations in the brain involve both auditory brain areas and non-auditory brain areas, including the limbic system and prefrontal cortex. The abnormalities found in these regions that are known as being part of emotion and attention networks probably explain the concentration problems frequently reported by tinnitus sufferers, e.g. inability to concentrate or reduced capacity to store and retrieve information from working memory (1). On the other hand, increasing evidence links chronic tinnitus with the attention process, leading authors to propose that attention deficits would affect the habituation process that normally prevents “phantom” auditory perception from reaching the auditory cortex and awareness (2).

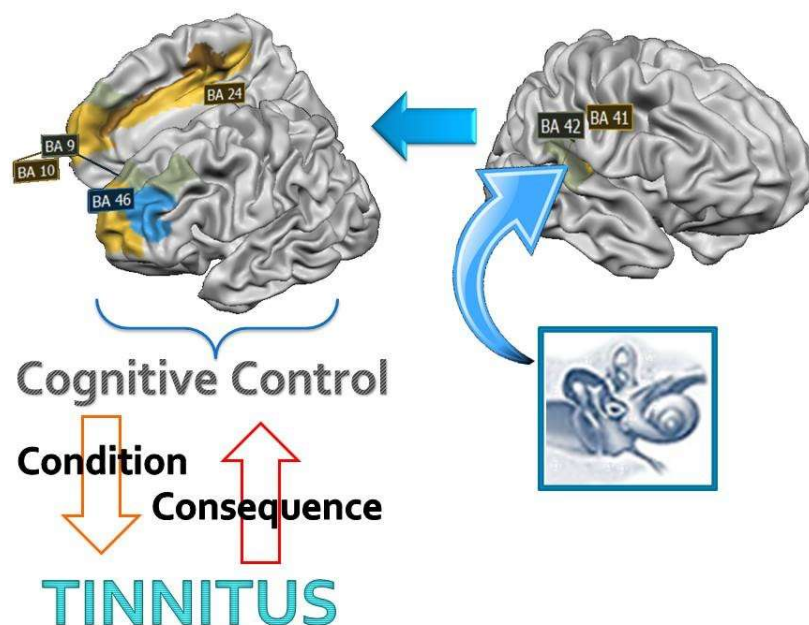


Figure 1. Schematic display of our hypothesis. We postulate that underperformance in the top-down cognitive control linked to alterations in prefrontal cortical areas would play a key-role in tinnitus generation and maintenance.

Here we evaluated the efficiency of the top-down cognitive control using the same behavioral tests, including a spatial Stroop, adapted in both the auditory and the visual modality, with the aim to identify which cognitive aspects were altered in tinnitus sufferers (Figure 1).

In this study we paid a particular attention to the inclusion criteria in order to homogenize the group of participants and to isolate tinnitus from potential confounding factors (such as depression, anxiety, hearing loss). Accordingly, we only included patients who suffered from a subjective and non-pulsatile tinnitus, that was present permanently (not by intermittence), for at least 6 months (chronic), in both ears (bilateral), who had either a normal hearing acuity or a slight hearing loss (i.e. average hearing loss inferior to 35 dB in each ear), without hyperacusis, with no record of neurological or diagnosed psychiatric disorder (including major depression) at the time of the testing, and without psychotropic medication consumption. Healthy controls were matched for age, gender, hearing acuity, handedness and educational level.

We used a spatial Stroop paradigm in which stimulus attributes (in this case stimulus location and stimulus meaning) were in conflict and interfered with the task to perform. We evaluated the efficiency of the top-down cognitive control in spatial Stroop conditions and also assessed such other cognitive processes as stimulus detection (the lowest level of sensory processing intended to serve as baseline) and stimulus processing speed (when no interference between stimulus attributes was present). Each condition was assessed in both the auditory and the visual modality.

Here we observed that tinnitus patients (TP) were slower and less accurate than control subjects (CS) during both the auditory and the visual spatial Stroop tasks (i.e. they were slower and made more errors in incongruent or interference trials), in particular during the stimulus recognition conditions (Figure 2).

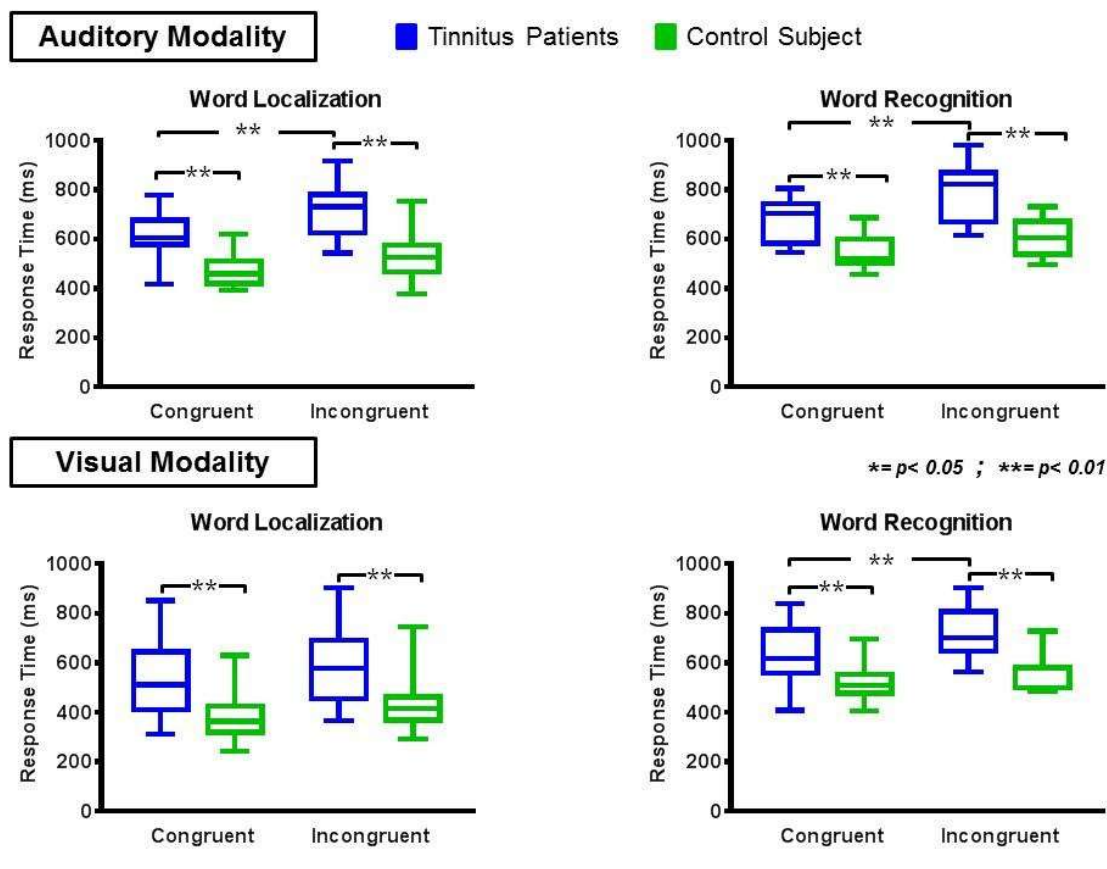


Figure 2. Response times during the spatial Stroop conditions in tinnitus patients and control subjects. Box-and-whisker plots represent the median and the maximal and minimal values for response times, which are displayed as a function of the group and the trial type (congruency of the stimulus attributes) during the stimulus localization (left) and the stimulus recognition (right) conditions, in the auditory (upper) and in the visual (bottom) modality.

In addition, TP showed longer response times to stimulus detection (simple reaction speed) and stimulus processing (stimulus localization and stimulus recognition) in the auditory modality only (Figure 3).

The observation of longer response times and lower accuracy rates in TP than CS during the spatial Stroop conditions in both the visual and auditory modalities indicates that top-down cognitive control mechanisms are impaired in tinnitus patients. This is consistent with the previously reported deficits that were observed in tinnitus patients when using classical Stroop tasks or the Attention Network Test (ANT) (3). Here we provided a demonstration that this top-down cognitive control deficit is primarily related to tinnitus and not to any of the co-morbidity conditions (depression, anxiety) that are frequently associated with tinnitus. Other factors affecting the performance to psychological tests (age, hearing acuity) were also controlled. In addition, although performance appeared slightly worse in the auditory modality, a deficit was present in both audition and vision, which is consistent with the idea according to which top-down cognitive control processes are supra-modal, exerting a control in all the sensory modalities. We observed a deficit in top-down cognitive control in tinnitus patients that was slightly more pronounced in the auditory modality: this is probably due to an additional decrease in its efficiency resulting from the interactions between (impaired) top-down cognitive control and (impaired) auditory stimulus processing. There were strong correlations for response accuracy between the visual and auditory spatial Stroop tasks within each group, indicating that a similar process was at work during the Stroop conditions in the two modalities.

Given the prominent role of the executive functions (also known as cognitive control or supervisory attention system) in the cognitive functioning, it is tempting to suggest that the specific deficit we observed here may explain the concentration difficulties often reported by tinnitus sufferers as well as their altered performances in attention tasks. In addition, it has been observed that tinnitus patients were more sensitive to cross-modal interference, in particular when a sound matched with tinnitus frequency was used as an irrelevant stimulus during a visual task (4). This converging evidence that the cognitive control is altered in tinnitus patients let us consider that it is a major component of the process that prevents phantom sensations like tinnitus to reach consciousness. A dysfunction of the top-down cognitive control could have an impact on the evaluation of stimulus relevance (i.e. the evaluation of stimulus salience) and/or in the inhibition of irrelevant information (i.e. the rejection of distractors), which could interfere with information processing, generating a delay in the response. In tinnitus patients, phantom sensations could be erroneously considered as a relevant stimulus, which would prevent the habituation process to occur and, therefore, let tinnitus reach consciousness. We postulate that alterations in cognitive control mechanisms would explain a lack of early inhibitory modulation of input to primary auditory cortex and, therefore, play a key-role in tinnitus generation and maintaining by hampering habituation mechanisms.

In conclusion, here we conducted some of the pioneer works on attention and cognitive control in tinnitus patients during the same auditory and visual tasks. The administration of an original battery of psychophysical tests allowed us to indubitably demonstrate that tinnitus sufferers have specific deficits in top-down cognitive control mechanisms, as shown by impaired performances in spatial Stroop. This selective cognitive impairment in executive function was found both in

the auditory and in the visual modality, leading us to postulate that the cognitive control, supra-modal in nature and known to recruit the prefrontal cortex, is a key-factor in the generation and maintaining of tinnitus. Additional investigations, with the aim to establish a direct link between behavioral performances in top-down cognitive control and brain alterations at the cortical level, should clarify the role of executive functions in chronic tinnitus, with the hope to develop new therapeutic targets.

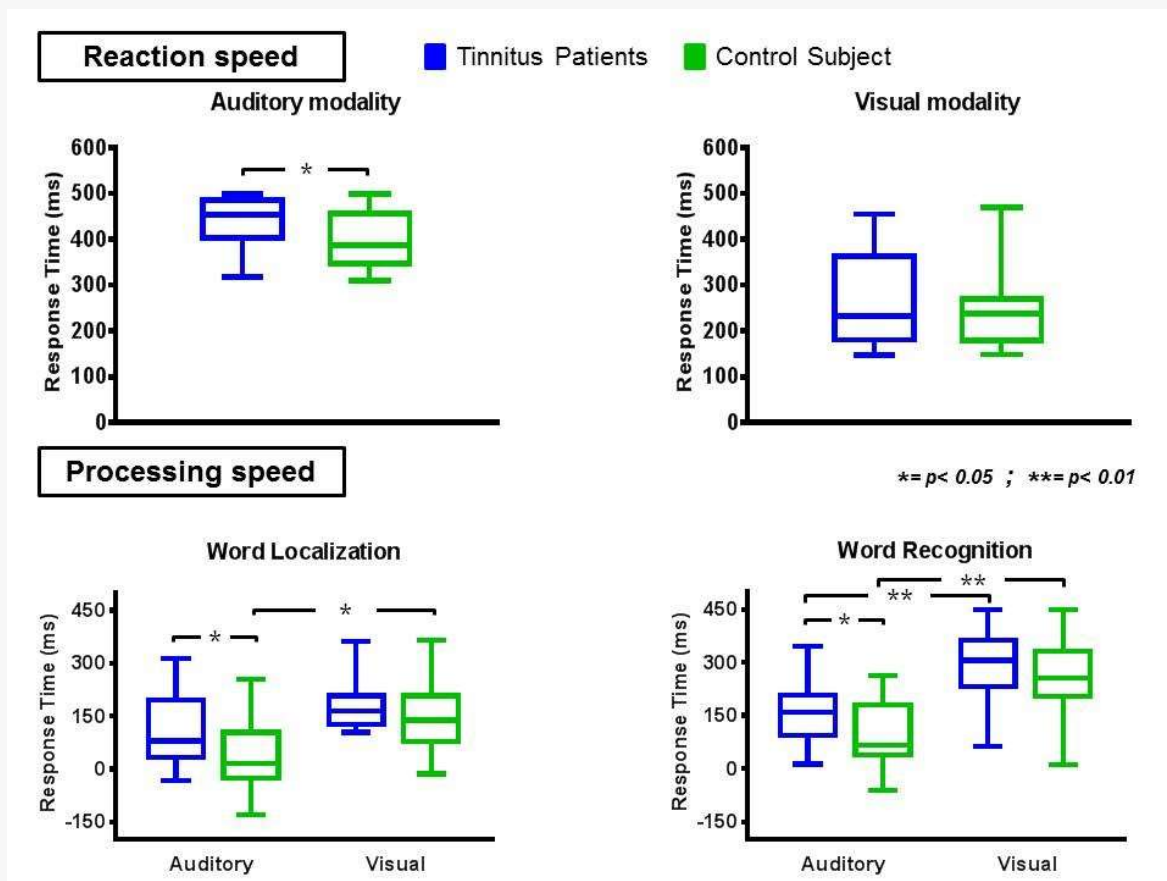


Figure 3. Response times during the stimulus detection and processing conditions in tinnitus patients and control subjects. Box-and-whisker plots represent the median and the maximal and minimal values for response times. The upper part of the figure shows the response times for the stimulus detection conditions (simple reaction speed) as a function of the group in the auditory (left) and in the visual (right) modality. The lower part of the figure shows the response times for stimulus processing as a function of the group and the sensory modality during stimulus localization (left) and recognition (right) conditions.

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Contact:

Anne G. De Volder, M.D., Ph.D.

Senior Research Associate (FNRS, Belgium) at the Université catholique de Louvain

Institute of Neuroscience

Avenue Hippocrate 54, UCL-B1.54.09,

B-1200 Brussels, Belgium

anne.de.volder@uclouvain.be

<https://www.uclouvain.be/en-msl-in.html>