



## Research report

# Tinnitus specifically alters the top-down executive control sub-component of attention: Evidence from the Attention Network Task



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## H I G H L I G H T S

- Impairment in attentional processes may be involved in tinnitus.
- Tinnitus patients (compared to controls) performed the Attention Network Test.
- A specific deficit for executive control of attention was observed.
- This deficit correlated with years of tinnitus duration and the frequency of coping strategies.

## A R T I C L E I N F O

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## A B S T R A C T

Tinnitus can be defined as the perception of noxious disabling internal sounds in the absence of external stimulation. While most individuals with tinnitus show some habituation to these internal sounds, many of them experience significant daily life impairments. There is now convincing evidence that impairment in attentional processes may be involved in tinnitus, particularly by hampering the habituation mechanism related to the prefrontal cortex activity. However, it is thus still unclear whether this deficit is an alteration of alerting and orienting attentional abilities, or the consequence of more general alteration in the executive control of attention. In the present study, 20 tinnitus patients were compared to 20 matched healthy controls using the Attention Network Test, to clarify which attentional networks, among alerting, orienting, and executive networks, show differences between the groups. The results showed that patients with tinnitus do not present a general attentional deficit but rather a specific deficit for top-down executive control of attention. This deficit was highly correlated with patient characteristics of years of tinnitus duration and the frequency of coping strategies employed to alleviate tinnitus distress in daily life. These findings are discussed in terms of recent neurobiological models suggesting that prefrontal cortex activity might especially be related to tinnitus habituation. Therapeutic perspectives focusing both on rehabilitation of the executive control of attention and neuromodulation are also discussed.

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## 1. Introduction

Tinnitus, which can be defined as the perception of noxious disabling internal sounds in the absence of corresponding external stimulation, has a lifetime prevalence of 16–21% [1]. While about 75–80% of the patients show some habituation to these internal sounds [2], tinnitus is associated with significant daily life impairment when such habituation fails, often leading to anxious and depressive states [3–6]. Understanding the origin and underlying

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mechanisms of chronic tinnitus thus constitutes a crucial challenge for current basic research, in view of the huge psychological consequences of this pathology.

Although uncertainty still abounds regarding the neurobiological mechanisms underlying tinnitus, there is now convincing evidence from functional neuroimaging [7–9] and neurophysiology [10] that this condition is related to abnormal functioning of the central auditory system. Moreover, during the last decades, several authors have argued that impairment in attentional processes may also be involved in tinnitus, particularly by hampering the habituation mechanism [11–13]. This involvement of non-auditory deficit is reinforced by the fact that tinnitus is not only related to abnormal activity in auditory, but also in non-auditory brain regions [8,14]. Centrally, alterations have been found in the prefrontal cortex [15–17], a region playing a crucial role in attentional processes [18,19]. As pointed out by several authors [17,20–24], these alterations might be specifically related to the prevention of tinnitus habituation as well as to its psychological consequences in the daily life.

These findings suggest that attention processes may play an important role in the maintenance, and perhaps the development, of the disorder. Although uncertainty still abounds regarding whether the former is a causal factor or a by-product of the disorder, it has been shown that patients with tinnitus exhibit attention deficits. However, while some studies showed that tinnitus leads to altered performance in selective [24], divided [25,26] and sustained [27] attention, other suggested that these alterations might rely on reduced top-down executive control (i.e. the ability to resolve conflicts among responses and voluntarily regulate the allocation of attention resources) rather than on attentional processes per se [26,28]. It has also been suggested that the attentional deficits in tinnitus may merely be part of a general impairment in speed processing [29]. As a consequence, it is still unclear whether these deficits are the consequence of a general alteration in the executive control of attention, the consequence of genuine alterations in a specific attentional ability, or merely the results of a general slowdown effect in cognitive processing.

A possible explanation for these discrepancies among earlier results is the use of very diverse tasks, simultaneously exploring several attentional abilities. These earlier studies were in fact not based on a firm theoretical model of attention and were thus not able to precisely compare the impairments across different sub-components of the attentional system. A more systematic and reliable exploration of the attentional system, based on a unified task relying on a cognitive model and offering a specific evaluation of each attentional sub-component, is clearly needed. The Attention Network Test (ANT) [30], based on a strongly validated model of attention [31,32], constitutes an adapted tool for this purpose. This task, based on a combination of the Posner's cueing task [33] and the Flanker task [34], efficiently evaluates the three independent attentional networks identified in the model, namely (1) The *alerting network*, allowing to achieve and maintain a state of alertness, i.e. high sensitivity or readiness to react to incoming stimulation; (2) The *orienting network*, allowing to select information from sensory input by engaging or disengaging attention to one stimulus among others and/or shifting the attentional resources from one stimulation to another; (3) The *executive control network*, allowing to resolve conflicts among responses and involving the top-down control of attention.

Typically, the different components of attention have been examined using different paradigms. Thus, three different tasks may be used to examine these attention components within the same individuals. In that case, it is not possible to examine how these components simultaneously interact. The ANT, however, allows the examination of these components all at once and to examine how they interact. It is noteworthy that neuroimaging

studies provided demonstration of distinct brain activation patterns related to each attentional network, i.e. superior temporal and thalamic activation for alerting, superior parietal lobule and temporal fusiform gyrus activation for orienting, thalamic and superior–inferior frontal activation for executive control [35].

Hence, the ANT has been recently used to differentiate the attention deficits associated with diverse neurological conditions. For instance, it has been reported that individuals with mild cognitive impairment exhibited a specific alteration of the orienting network [36], while multiple sclerosis led to a specific impairment of the alerting network [37]. Similarly, this task has been also used across a wide range of psychiatric conditions. For instance, while autism spectrum disorders are associated with a global impairment of the three attentional networks [38], a specific impairment in the executive control network was found in schizophrenia [39], addiction [40], and anxiety disorders [41].

Although the ANT could bring insights on the hypothesized impact of tinnitus on attentional processes, this task has surprisingly not yet been used among individuals with tinnitus. The aim of the present study was to offer the first insights into the integrity or deficit of the three attentional networks in tinnitus. In order to better understand the attentional impairments in this pathology, we wished to explore the hypothesis of a differential deficit between these networks. Since previous data suggested that tinnitus depletes top-down executive resources that are recruited during an attentional task [25,26,29] and since this condition is related to less activation in frontal brain areas [15–17], we hypothesized that patients with tinnitus would present a specific deficit for the executive control network, as this network mostly relies on frontal areas.

## 2. Materials and methods

### 2.1. Ethics Statement

Participants were provided with full details regarding the aims of the study and the procedure. All participants gave their written informed consent. The study was approved by the Ethical Committee of the Psychological Science Research Institute of the Université Catholique de Louvain and carried out according to the Declaration of Helsinki.

### 2.2. Participants

The participants were recruited through an advertisement sent to the Belgian Association of Patients suffering from Tinnitus. The inclusion/exclusion criteria were similar to previous studies in the field [29,42]. Eligible participants (a) were between the age 20 and 80 years old, (b) had experienced constant unilateral or bilateral tinnitus within the past 6 months, (c) undertook a medical check-up by a physician specialized in hearing disorders, (d) had sufficient hearing abilities to follow the instructions. Participants were excluded if (a) there was an active diagnosis of any acute or chronic brain neurological condition; (b) they used a tinnitus masking apparatus, or (c) they presented major general cognitive impairment. This last aspect was evaluated using the Mini Mental State Exam (MMSE) [43], a semi-structured neuropsychiatric interview. All the participants reported a MMSE score above 27/30, which depicted the absence of any major cognitive impairment (i.e., scores below 24/30 are considered a problematic) [43]. Tinnitus characteristics and impact on daily life were assessed using the Tinnitus Psychological Impact Questionnaire (QIPA; see below) [44].

The clinical group of Tinnitus subjects (TS) consisted of 20 participants (10 men, 10 women) aged between 20 and 72 years old ( $M = 46.85$ ,  $SD = 15.79$ ). Patients were matched for age, gender, and

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