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Cognitive Speed as an Objective Measure of Tinnitus

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Abstract

Background—Subjective, chronic tinnitus is a common but poorly understood condition. The heterogeneity within tinnitus has hindered the development of functional severity measures and effective treatment. Tinnitus at least partially results from maladaptive cortical processes that are associated with cognitive deficits. This study examined whether cognitive processing speed might serve as a novel objective measure of tinnitus severity, and whether the psychiatric co-morbidities of depression and somatization are predictive of self-reported tinnitus severity.

Study Design—Cross-sectional study of 92 chronic tinnitus participants.

Methods—The Tinnitus Handicap Inventory (THI) captured the self-reported severity of tinnitus. Cognitive processing speed was objectively measured by the Brain Speed Test (BST), a short computerized test from Posit Science®. Somatization and depression were captured by the Whiteley-7 and Patient Health Questionnaire-9 (PHQ-9) scales. The results of these tests were combined into a Composite Psychiatric State (CPS) variable. The ability of *BST Z-score* and *CPS Level* to predict THI was assessed.

Results—There was a significant correlation ($r=0.54$, $p<0.001$) between *BST Z-scores* and THI in those with bothersome tinnitus (THI ≥ 30). Additionally, *BST Z-score* was correlated with the validated neuro-cognitive tests. Multivariate analysis identified *BST Z-score* and *CPS Level* as independent predictors of THI.

Conclusions—In severe tinnitus, BST provides as an objective measure of the functional impact of tinnitus. Cognitive processing speed and psychiatric state are independent predictors of self-reported tinnitus severity. These measures help define clinical subgroups within tinnitus- one subgroup whose functional impact is primarily cognitive and another whose functional impact is primarily psychiatric.

Keywords

tinnitus; cognition; depression; somatization

INTRODUCTION

Chronic tinnitus is a widespread condition with an estimated prevalence of 10–15%. While most people experience minimal impact on their quality of life, tinnitus is a clinically

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significant condition for 20% of those with chronic tinnitus.¹ Tinnitus can have many different effects on patients, including interference with concentration and speech, annoyance, and insomnia.^{2–5} A large variation exists in the extent to which patients say these symptoms and impairments accompany their tinnitus.⁶ Although the neurobiology of tinnitus is not well understood, current research focuses on a central-origin hypothesis, looking at the auditory cortex, or other higher order regions of the brain as the etiology of tinnitus.⁷ An obstacle in understanding chronic tinnitus is that it represents a heterogeneous group of distinct clinical subgroups. Better delineation of these subgroups is an essential step in developing treatment for tinnitus as evidence suggests that the subgroups respond differently to various management approaches.^{8,9}

Several studies have investigated the cognitive deficits associated with chronic tinnitus, particularly in the domains of attention and processing speed. Researchers^{10,11} used the Stroop test, a well-established paradigm used to measure selective attention, to demonstrate that tinnitus patients perform worse than healthy controls, suggesting that the tinnitus percept serves as a distraction from task performance.¹² A study of selective and divided attention further supports the idea that a constant tinnitus stimulus depletes attention resources that are available for other tasks.¹³ Besides attention, studies also indicate that tinnitus impairs cognitive processing speed. Tinnitus patients performed slower than healthy controls in measures of cognitive efficiency.¹⁴ After controlling for IQ and anxiety levels, tinnitus patients exhibited decreased processing speed and accuracy in a dual task paradigm.¹⁵ As Andersson and McKenna¹⁶ stated in their review, “the literature increasingly shows that tinnitus and cognition are inseparable,” and investigating cognitive deficits is critical in understanding why tinnitus is so bothersome to some.

No study has tried to use the cognitive deficits associated with tinnitus as an objective measure of tinnitus severity. Measuring loudness, pitch, and other characteristics of the tinnitus percept would seem to be a logical method to establish an objective measure of tinnitus severity. However, past studies of those psychoacoustic measures failed to show a consistent relationship with the severity of tinnitus.^{17,18} In order to assess tinnitus severity and response to potential therapies, researchers and clinicians have relied on subjective questionnaires such as the Tinnitus Handicap Inventory (THI)¹⁹ and, more recently, the Tinnitus Functional Index.²⁰ While several questionnaires have been published, Henry et al. noted in his review article²¹ that the considerable heterogeneity within tinnitus has prevented a consensus about which questionnaire is properly quantifying tinnitus severity. Depression and somatization are two psychiatric co-morbidities in particular that are frequently associated with chronic tinnitus^{22,23}, and the psychiatric state of tinnitus patients greatly influences how they perceive and react to tinnitus.^{21,24} Thus, an objective measure, one that relies less on the patient’s perception to quantify functional impact, would be useful in understanding the multidimensional nature of tinnitus and guiding treatment decisions.

This study utilized the Brain Speed Test (BST), a computerized assessment developed by Posit Science®. BST measures attention and cognitive processing speed specifically through the auditory domain by having the participant recognize crescendo or decrescendo sound sweeps. While tinnitus is a subjective perception, measuring cognitive deficits may objectively measure the impact of tinnitus on a patient’s life. BST requires no trained personnel to administer and grade and is freely available through Posit Science’s website [<http://www.positscience.org/>]. The presence and severity of depression and somatization were assessed to understand the psychiatric state of the participants. This study investigated the relationship between self-reported tinnitus severity, cognitive processing speed, and psychiatric co-morbidities. Our hypothesis is that the cognitive impact of tinnitus can be demonstrated by slow processing speeds after controlling for depression and somatization.

METHODS

Design

This was a cross-sectional study designed to investigate the relationship that self-reported tinnitus severity has with cognitive processing speed and psychiatric factors. The study was approved by the Human Research Protection Office of Washington University in St. Louis and was listed at Clinicaltrials.gov [NCT01395368].

Study Population

Participants were enrolled from the clinical practices and special volunteer registries at Washington University Medical Center, a tertiary care medical center, from May to September 2011. Eligible participants were between the ages of 30 and 80 years and had subjective, unilateral or bilateral, nonpulsatile tinnitus of 6 months' duration or longer. Participants were excluded if there was an active diagnosis of any acute or chronic brain-related neurological condition, or a history of neurological surgery, skull fracture, or retrocochlear lesion. An audiogram was performed on all participants. Those who could not hear the auditory stimuli of the Brain Speed Test were excluded. Additionally, participants were excluded if they could not read, write, and speak English. Participants taking any medications which would interfere with performance on neuro-cognitive tests, such as sedatives or opiates, were also excluded.

Measurements

Population and tinnitus characteristics were collected using a demographics form and the Tinnitus Description and History form from the Oregon Hearing Research Center [<http://www.tinnitusarchive.org/forms/>]. The Tinnitus Handicap Inventory (THI)¹⁹ served as the primary outcome measure for tinnitus severity. The THI is composed of 25 questions with three potential responses: *Yes*, *Sometimes*, and *No*. A 5-point Likert Global Severity Rating Scale named (the *Overall Bother* level) was used to assess the overall degree of tinnitus bother with "1" indicating *No Bother* and "5" indicating *Severe Bother*. The Tinnitus Functional Index (TFI), a recently validated self-report tinnitus severity instrument was also administered.²⁰ The THI has been criticized for its lack of sensitivity since the respondent is limited to three choices²⁵; the TFI utilizes a 10-point interval scale for each question.

Performance on the BST was captured as an objective measure of cognitive processing speed. In the BST, participants have to identify sound sweeps as either rising or falling in pitch. BST was administered using a standard computer with noise-cancelling headphones. Participants with a severe level of hearing loss on the audiogram or using hearing aids were excluded. Participants were allowed to adjust the volume to a level that allowed them to comfortably hear the stimuli during a tutorial. By completing the tutorial, participants demonstrated that they understood the task and could hear the stimuli. During the test, the sound sweeps increased in speed to the point where the participant could no longer correctly identify the direction of the sound sweep. Thus, the test identified the fastest sweep whose direction could be correctly identified by a participant. To complement BST, the following battery of validated neuro-cognitive tests were also administered: the Stroop Color Word Test (SCWT)^{10, 11}, the Paced Auditory Serial Addition Test (PASAT)²⁶, and A Quick Test of Cognitive Speed (AQT).²⁷ These tests were selected because they specifically measure the cognitive domains of processing speed and attention. Depression was measured using the Patient Health Questionnaire-9²⁸, and the presence and severity of co-existing functional somatic syndromes was measured using the Whiteley-7 Scale.²⁹ Hearing level was defined as the pure-tone average of 1000, 2000, and 4000 Hertz in the worse ear, and hearing loss was classified as None (−10 to 15 dB), Slight (16 to 25 dB), Mild (26 to 40 dB), Moderate (41 to 55 dB), Moderate/Severe (56 to 70 dB), Severe (71 to 90 dB), or Profound (>90dB).

Analysis

Standard descriptive statistics were used to describe the characteristics of the study population and the distribution of test scores. The independent samples t-test was used to compare the distribution of continuous level variables between bothered and non-bothered participants, and the χ square test was used for comparing the distribution of categorical variables. BST scores, reported in milliseconds, were transformed to Z-scores representing the distance, in standard deviations, from the mean age-specific BST scores provided by Posit Science.

A pilot study conducted at our institution investigating BST as an objective measure of tinnitus revealed that the test exhibits a threshold effect, correlating with THI scores in those above a certain level of tinnitus severity.³⁰ In that study, the investigators found that there was a significant relationship between *BST Z-scores* and THI scores in participants with bothersome tinnitus (THI ≥ 30) but not in the participants that were not bothered from tinnitus as measured by the THI score. We explored the relationship between self-reported measures of tinnitus (THI) and *BST Z-Scores* using Pearson correlation in the bothered group (THI ≥ 30) and the non-bothered group (THI < 30). Pearson correlation was also used to assess the bivariate relationship between scores obtained on BST and each of the neurocognitive tests - SCWT, PASAT, and AQT.

The PHQ-9 and Whiteley-7 scales, measuring depression and somatization, represent the most relevant psychiatric characteristics of participants. Depression and somatization affect the way the participants respond to the tinnitus percept, and consequently, their self-reported severity. A statistical technique known as conjunctive consolidation³¹ was used to combine the PHQ-9 scores and Whiteley-7 scores into a single composite variable, the *Composite Psychiatric State (CPS)*, which represents the participant's depression and somatization levels. Conjunctive consolidation has been used for a variety of research purposes, including the inclusion of co-morbidities into prognostic cancer staging systems.^{32, 33}

Multivariate linear regression was implemented to assess the role of *BST Z-scores* and the *CPS Level* in predicting THI. Alpha level for all statistical tests was set at 0.05. All statistical analyses were performed using SPSS 19.

RESULTS

A total of 181 potential participants were screened by telephone for entrance into the study and 96 participants completed the study. There were 92 included in analysis (Figure 1). Four of those participants were excluded from analysis involving BST, since they were younger than the normative age-specific data available and *BST Z-scores* were not able to be calculated. Of the 92 participants, 40% (n=37) were bothered by their tinnitus (THI ≥ 30). A minority (14%) of participants had no hearing loss (< 10 dB), 33% had a slight hearing loss, 39% had a mild hearing loss, and 14% had a moderate or moderate/severe hearing loss (Table I and II).

BST Performance

There was no significant correlation in *BST Z-score* and THI scores in the non-bothered group. In the bothered group, however, THI scores and *BST Z-score* were significantly correlated ($r=0.54$, $p = 0.001$). In other words, participants who had more severe tinnitus (i.e. high THI scores) had longer reaction times on BST (Figure 2). In the bothered group, THI scores and BST Z-scores were also significantly correlated ($r=0.51$, $p = 0.001$). BST is a new test that has not been established in the literature and so we compared it to established cognitive tests (Table III). *BST Z-Score* had significant moderate correlations (r value range

from 0.274 to 0.465) to all cognitive tests that were administered, where worse performance on the BST was associated with worse performance on each of those tests.

Conjunctive Consolidation of Depression and Somatization

In the bothered tinnitus group ($THI > 30$), increasing PHQ-9 and Whiteley-7 scores were generally associated with higher THI scores (Figure 3). For instance, participants with lower levels of depression and absence of somatization had, on average, the lowest THI scores (mean score=36). While, participants with both high levels of depression and presence of somatization had the highest THI scores (mean score = 54).

The six categories of depression and somatization were consolidated into three groups, or *Composite Psychiatric State (CPS) Levels*. (Figure 4) The goal of this consolidation was to take a heterogeneous population and put them in groups that are “externally disparate but internally homogenous with respect to outcome.”³² The THI gradient across the groups is monotonic meaning the change in THI score increases as the group increases from I to III. Participants in *CPS Level I* had the lowest mean THI score (36), participants in *CPS Level III* had the highest mean THI score (52), while participants in *CPS Level II* had intermediate THI scores (42). This relationship achieved statistical significance [ANOVA analysis $F=8.2$, $p=0.001$]. The percentage of participants who were at least “*Bothered A Lot*,” i.e. 4 out of 5 on the *Overall Bother* score, also increased monotonically across the three levels (range from 7% to 56%; Cochran-Armitage test for linear trend p -value=0.008).

Multivariate Analysis

Multivariate linear regression was used to investigate whether the psychiatric factors and cognitive processing speed predict a participant’s self-reported tinnitus severity. *CPS Level* (categorically defined) and *BST Z-scores* (continuously defined) were entered into a model to predict THI. The overall model was significant with an F value of 8.82 ($df=3$, $p<0.001$). After controlling for the *CPS Level*, the *BST Z-score* was a significant predictor ($b=8.3$, 95% $CI=1.97$ to 14.58). For each 1-point increase in *Brain Speed Z-score*, the THI increased by 8.3 points. After controlling for *BST Z-scores*, the *CPS Level* remained an independent significant predictor of THI. A subject in *CPS Level III* is predicted to have a 12-point higher THI than a subject in *CPS Level I* with the same *BST Z-score* ($b=12$, 95% $CI=3.42$ to 20.65), and a subject in *CPS Level II* is predicted to have a 7-point higher THI score than a subject in *CPS Level I* with the same *BST Z-score* ($b= 6.9$, 95% $CI= -0.07$ to 13.96).

DISCUSSION

In this study, we found that among a cohort of bothered tinnitus participants, the severity of cognitive processing deficits is related to severity of self-reported tinnitus bother. Secondly, we consolidated depression and somatization into a single composite variable that we believe represents the psychiatric characteristics that influence how a person responds to the tinnitus percept. Both cognitive processing speed and psychiatric distress were independently predictive of the participant’s self-reported tinnitus severity. If these results are validated, it would suggest that including objective measures of cognitive impairment, like BST, and self-reported measures of depression and somatization should be included in clinical studies of tinnitus so as to better define the tinnitus patient. In so doing, this expanded classification would allow for better assessment of treatment effectiveness and development of patient-specific treatment strategies.

Tinnitus patients often complain of cognition difficulties. The findings of this study, which show that tinnitus severity is associated with deficits in cognitive processing speed and attention, corroborate earlier studies examining cognition performance in tinnitus

patients.^{13, 15} As we learn more about the neurobiology of tinnitus, increasingly maladaptive neuroplastic changes are thought to be a critical part of the tinnitus percept.³⁴ Thus, researchers place an increasing emphasis on central sites for the origin and maintenance of tinnitus, rather than inner ear pathology. Therefore, it makes sense that the aberrant neuroplastic changes of tinnitus are associated with cognitive deficits. We believe the severity of neurocognitive changes can serve as a surrogate measure of tinnitus severity.

The existence of a psychiatric component to tinnitus is well known. Depression and somatization have been shown to be more common in tinnitus patients than healthy controls.^{23, 24} Newman et al.³⁵ used somatization and self-focused attention indices in a cluster analysis to create groupings within tinnitus patients. They used depression and the Tinnitus Handicap Questionnaire as outcome measures to demonstrate a difference between the two groups. While our study was similar in Newman's, we used both a depression and somatization scale to create a single variable, which we found to be predictive of self-reported tinnitus severity.

One limitation of this cross-sectional study is that any causal direction between cognitive deficits and tinnitus cannot be inferred. However, finding an association between the two is still an important result as our focus is on measuring tinnitus severity. Another limitation is that the BST exhibits a threshold effect and is only useful in patients with a certain level of bother (THI ≥ 30). This finding was first reported in a pilot study (n=60).³⁰ The failure to find a relationship between BST and tinnitus patients with little or no bother is not as critical as it is the bothered patients that generally seek medical attention. Secondly, BST is not a validated test of cognitive processing speed or attention. For that reason, we compared the performance of the BST to established neurocognitive tests (SCWT, PASAT and AQT) to assess its validity.

The separate identification and inclusion of depression and cognitive speed has the practical utility of assisting in the management of tinnitus patients. For example, if a patient had a high level of psychiatric reaction to the tinnitus but few cognitive processing changes, psychological therapy, cognitive behavioral therapy, rTMS to the dorsolateral prefrontal cortex, or antidepressants may be a reasonable start to therapy. On the other hand, if the psychiatric component is minimal but cognitive slowing is more prominent, an approach utilizing cognitive rehabilitation training may be more likely to work.

CONCLUSION

Understanding the heterogeneity within chronic tinnitus and identifying distinct clinical subgroups is important for the development of better treatment strategies of the condition. This study identifies two dimensions that are independently predictive of self-reported tinnitus bother: the cognitive processing speed associated with tinnitus and a psychiatric component consisting of depression and somatization levels. Thus, these two dimensions help to better define the impact tinnitus has on a patient's life. Future studies should validate the finding that cognitive impairment and psychiatric factors independently predict self-reported tinnitus severity.

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Figure 1.
Flow diagram of participant recruitment and screening/exclusion.

Figure 2.

Scatter plot of participant performance on Brain Speed Test versus self-reported tinnitus. BS Z = Brain Speed Test Z-score. THI = Tinnitus Handicap Inventory score

		PHQ-9 Scale Score			Total
		0-2	3-5	≥6	
Whiteley-7 Scale Score	0	N = 13 THI = 36 Bother = 8%	N = 2 THI = 33 Bother = 0%	N = 2 THI = 48 Bother = 0%	N = 17 THI = 37 Bother = 6%
	≥1	N = 5 THI = 45 Bother = 40%	N = 8 THI = 40 Bother = 50%	N = 7 THI = 54 Bother = 71%	N = 20 THI = 46 Bother = 55%
Total		N = 18 THI = 39 Bother = 17%	N = 10 THI = 39 Bother = 40%	N = 9 THI = 52 Bother = 56%	N = 37 THI = 42 Bother = 32%

Figure 3.

Self-reported tinnitus bother for a given level of severity of depression and somatization. Cells from left to right represent increasing levels of depression, as measured by the Patient Health Questionnaire-9. Cells from top to bottom represent absence versus presence of somatization, as measured by the Whiteley-7 Scale. PHQ-9 = Patient Health Questionnaire-9. THI = mean Tinnitus Handicap Inventory score. Bother = percentage of participants for a given category who are at least “*Bothered A Lot*” on *Overall Bother* scale.

		PHQ-9 Scale Score		
		0-2	3-5	≥6
Whiteley-7 Scale Score	0	I. N = 15 THI = 36 Bother = 7%		III. N = 9 THI = 52 Bother = 56%
	≥1	II. N = 13 THI = 42 Bother = 46%		

Figure 4. Conjunctive consolidation of depression and somatization into 3 levels (I – III) of *Composite Psychiatric State*. PHQ-9 = Patient Health Questionnaire-9. THI = mean Tinnitus Handicap Inventory score. Bother = percentage of participants for a given category who are at least “*Bothered A Lot*” on *Overall Bother* scale.

TABLE I**Population Characteristics**

	All N=92 Frequency (%)	Non-bothered (THI<30) N=55 Frequency (%)	Bothered (THI ≥ 30) N= 37 Frequency (%)	p-value
Gender				0.2
Male	56 (61)	36 (66)	20 (54)	
Age, mean (SD), y	53 (SD 8)	55 (SD 8)	50 (SD 8)	<0.01
Race				0.7
White	84 (91)	51 (93)	33 (37)	
Other	8 (9)	4 (7)	4 (50)	
Education Level				0.8
High School/Associate Degree	34 (37)	19 (35)	15 (41)	
Bachelor's Degree	32 (35)	20 (36)	12 (32)	
Master's Degree or Higher	26 (28)	16 (29)	10 (27)	
PHQ-9 Score				0.05
0–2	56 (61)	38 (69)	18 (49)	
3–5	23 (25)	13 (24)	10 (27)	
6	13 (14)	4 (7)	9 (24)	
Whiteley-7 Scale Score				0.2
0	50 (54)	33 (60)	17 (46)	
1	42 (46)	22 (40)	20 (54)	
Hearing Loss Level*				0.7
None (–10 to 15 dB)	13 (14)	8 (15)	5 (14)	
Slight (16 to 25 dB)	30 (33)	20 (36)	10 (27)	
Mild (26 to 40 dB)	36 (39)	19 (35)	17 (46)	
Moderate/Severe (≥ 41 dB)	13 (14)	8 (15)	5 (14)	

THI = Tinnitus Handicap Inventory, PHQ-9 = Patient Health Questionnaire-9,

SD = standard deviation, y = years

* Defined as pure-tone average of 1000, 2000, and 4000 Hertz in the worse ear

TABLE II

Tinnitus Characteristics

	All N=92 Frequency	Non-bothered (THI<30) N=55 Frequency	Bothered (THI ≥ 30) N=37 Frequency	p-value
Duration, mean (SD), y	13.6 (14)	13.2 (14)	14.1 (13)	0.7
Tinnitus as a Significant Problem, mean (SD), y	7.6 (11)	4.7 (10)	11.9 (12)	<0.01
Loudness Scale *, mean (SD)	5.8 (1.7)	5.4 (1.6)	6.4 (1.6)	<0.01
THI Score, mean (SD)	27 (15)	18 (7)	42 (12)	N/A
TFI Score, mean (SD)	31 (17)	22 (13)	43 (16)	<0.001
Effort to Ignore				<0.001
Can ignore it with no/slight effort	35 (38%)	31 (56%)	4 (11%)	
Can ignore it with some effort	43 (47%)	20 (36%)	23 (62%)	
Can ignore it with considerable effort/never ignore it	14 (15%)	4 (7%)	10 (27%)	
Interference with Sleep				<0.001
No	36 (39%)	31 (56%)	5 (14%)	
Yes, sometimes	42 (46%)	21 (38%)	21 (57%)	
Yes, often	14 (15%)	3 (6%)	11 (30%)	
Overall Bother				<0.001
Not bothered/Bothered a little	31 (34%)	29 (53%)	2 (5%)	
Bothered more than a little but not a lot	48 (52%)	25 (46%)	23 (62%)	
Bothered a lot/Extremely bothered	13 (14%)	1 (2%)	12 (32%)	

SD =standard deviation, y = years, THI = Tinnitus Handicap Inventory

* Range 0 (quite) to 10 (loud). Percents may not equal to 100 due to rounding.

TABLE III

Correlation of Neuro-cognitive Tests with BST Z-scores *

	r	p-value
Stroop Color-Word T-Score	-0.340	0.001
Stroop Interference T-Score	-0.274	0.008
PASAT 2.4 Z-Score	-0.419	<0.001
PASAT 2.0 Z-Score	-0.462	<0.001
PASAT 1.6 Z-Score	-0.362	<0.001
PASAT 1.2 Z-Score	-0.339	0.001
AQT Color-Form Task Time *	0.458	<0.001
AQT Color-Number Task Time *	0.465	<0.001
AQT Color-Letter Task Time *	0.460	<0.001

BST = Brain Speed Test, PASAT = Paced Auditory Serial Addition Test AQT = A Quick Test of Cognitive Speed

* Higher test score indicates worse performance