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RESEARCH PAPER

A cross-sectional study on predictors of patients' tinnitus severity

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Abstract

Objective: To identify factors that influence the severity of tinnitus via a hierarchical multiple linear regression model.

Methods: The study was a retrospective cross-sectional analysis. The study included 331 patients experiencing tinnitus as their primary concern, who visited Shanghai Changzheng Hospital of the Navy Medical University between 2019 and 2021. Data on general health status and disease characteristics were collected from all patients. With their consent, participants underwent audiological evaluatons and completed questionnaires to analyze the characteristics of their tinnitus and the factors influencing its severity.

Results: The correlation analysis showed a positive relationship between tinnitus frequency, tinnitus loudness, SAS scores, and PSQI scores with THI scores ($P < 0.05$) among nine examined variables (gender, handedness, employment status, age, BMI, tinnitus frequency, tinnitus loudness, SAS scores, and PSQI scores). The variables that were extracted from the multiple regression were; for the constant; $\beta = -51.797$, $t = -4.484$, $P < 0.001$, variable is significant; for the tinnitus loudness; $\beta = 0.161$, $t = 2.604$, $P < 0.05$, variable is significant; for the tinnitus frequency; $\beta = 0.000$, $t = 1.269$, $P = 0.206$, variable is not significant; for the SAS scores; $\beta = 1.310$, $t = 7.685$, $P < 0.001$, variable is significant; for the PSQI scores; $\beta = 1.680$, $t = 5.433$, $P < 0.001$, variable is significant. Therefore, the most accurate model for predicting severity in tinnitus patients is a linear combination of the constant, tinnitus loudness, SAS scores, and PSQI scores, $Y\ (Tinnitus\ severity) = \beta_0 + \beta_1(Tinnitus\ loudness) + \beta_2(SAS\ scores) + \beta_3(PSQI\ scores)$. β_0, β_1, β_2, and β_3 are −51.797, 0.161, 1.310 and 1.680, respectively.

Conclusion: Tinnitus severity is positively associated with loudness, anxiety levels, and sleep quality. To effectively manage tinnitus in patients, it is essential to promptly identify and address these accompanying factors and related symptoms.

Teng-Fei Li, Xu-Dong Cha, and Tian-Yu Wang have contributed equally to this work and share the first authorship.

KEYWORDS
hierarchical, multiple linear regression, tinnitus

INTRODUCTION

Derived from the Latin verb "tinnire," which means to ring, the term tinnitus is a condition that a person perceives sound without any internal or external source. Studies have shown that tinnitus affects between 10% and 15% of the adult population.[1] In England, the National Research of Hearing conducted a credible scientific study that revealed an adult prevalence of 10.1%.[2] Similar prevalence rates have been reported in studies conducted in the United States and China.[3,4]

Tinnitus is not a disease but a symptom that can significantly affect a person's quality of life. Although it is not usually associated with severe medical conditions, its impact should not be underestimated. Most cases of tinnitus are idiopathic and related to sensorineural hearing loss, including presbycusis and noise-induced hearing loss.[5] The precise pathophysiology of primary tinnitus is usually unclear and is likely multifactorial. It is believed that tinnitus is a phantom sensation caused by abnormal neural activity in the auditory nerve, the central nervous system, or the ear.[6,7]

In China, tinnitus is commonly treated with tinnitus habituation therapy and sound therapy. Cognitive behavior therapy has shown moderate to high-quality evidence of benefits to the primary tinnitus outcome, often referred to as tinnitus distress. This treatment approach also appears to have benefits for other tinnitus-related conditions, such as mood and cognitive disorders, sleep disturbance, depression, and anxiety.[8] As basic research in neuroscience continues, plenty of evidence proves that adequate diagnosis and treatment of psychosomatic disorders associated with tinnitus can significantly improve patients' quality of life.[9,10] However, the correlation between tinnitus and psychosomatic disorders in patients has not been well-studied, especially for the models used to predict the severity of tinnitus.

The aims of this study were to determine the factors predicting the severity of tinnitus using a hierarchical multiple linear regression model and to evaluate the weight of each factor. Our goal is to discover a simplified representation among the complex and heterogeneous disease factors and to provide it with clinical significance.

METHODS

Study design and participants

This retrospective cross-sectional study was conducted at the Department of Otorhinolaryngology, Shanghai Changzheng Hospital. The study included 331 patients who visited the clinic between April 2019 and February 2021 with tinnitus as their primary complaint. All data were based on the initial assessment of the patients before any treatment. All participants completed audiological measurements and structured close-ended interviewer-administered questionnaires. All the audiological measurements were conducted by the same experienced audiologist, including the pure-tone audiometry, tinnitus pitch matching, and tinnitus loudness matching.[11] All questionnaires were provided in a pen-and-paper format and completed independently by patients.

Inclusion and exclusion criteria

Inclusion criteria: tinnitus as the only audiological primary complaint; complete the questionnaire independently and thoroughly; 18 years of age or older; sign the consent form with full understanding.

Exclusion criteria: objective tinnitus or somato-sounds; sensorineural hearing loss (particularly during the acute phase); acute or chronic external or media otitis; middle ear cholesteatoma; otosclerosis; Meniere's disease; history of ear trauma or surgery; severe cardiovascular and cerebrovascular diseases; severe mental diseases or undergoing antianxiety or depression treatment; drug-induced tinnitus; inability to complete the questionnaires or cooperate with audiological and tinnitus tests; research physician deemed the subject unsuitable for participation based on medical inquiry, physical examination, and screening test results.

Sample size

A common rule of thumb for determining the required sample size is to have at least 10 events for each predictor parameter, this is widely referred to as needing at least 10 events per variable (10 EPV).[12,13] As a general rule, with nine predictive variables, a sample size of at least 90 is needed. Furthermore, the sample size was theoretically calculated using the pwr package in R language, with a linear multiple regression model. The statistical significance level was set at $\alpha = 0.05$, the effect size at $f^2 = 0.15$, the statistical power $(1-\beta)$ of 0.80, and total predictor numbers of 9. A minimal sample size of 113 was established theoretically.

Audiometry

All audiological measurements took place in a soundproof booth that fulfilled standard acoustic requirements.

Pure-tone audiometry: pitches of 125, 250, 500, 1000, 2000, 4000, and 8000 Hz (air conduction) and 250, 500, 1000, 2000, and 4000 Hz (bone conduction) were tested, with the latter being performed only if the individual had an auditory threshold greater than 25 dB HL. The descending-ascending approach was employed to determine the auditory threshold. Calculating the mean pure-tone air conduction (PTA) threshold at 500, 1000, and 2000 Hz allowed researchers to identify hearing impairment. PTA threshold means ≤ 25 dB HL were normal, and ≥26 dB HL were assessed as having hearing loss.

Tinnitus pitch and loudness matching: briefly, it was explained to the patients that the sound that most closely mirrored their tinnitus would be investigated. The sound was presented to the normal ear or with the less tinnitus loudness. The patient chose between two different sounds, for example a 125-Hz sound, and another of 8,000 Hz, and was asked "which of these sounds most closely like your tinnitus?" The pitch was expressed in Hz, corresponding to the perception of tinnitus frequency. Next, loudness was investigated, with an increase in sound loudness given at every 1 dB HL. The result was expressed in dB HL.

Tinnitus handicap

The severity of tinnitus in daily living was assessed using the Tinnitus Handicap Inventory (THI).[14] The Chinese-Mandarin version of the THI has a high test–retest ($r = 0.98$) and internal consistency reliability ($\alpha = 0.93$).[15] The THI scale consists of three subscales, including functional, emotional, and catastrophic subscales, and features 25 items with a total score of 100 points. Scores ranging from 0 to 16 indicate no handicap, 18–36 indicate a mild handicap, 38–56 indicate a moderate handicap, 58–76 indicate a severe handicap, and 78–100 indicate a catastrophic handicap.

Assessment of anxiety

The Self-rating Anxiety Scale (SAS) was used to evaluate the patients' anxiety levels over the previous 7 days.[16] The SAS scale consists of 20 items, each scored on a scale ranging from one and four. "No or little time" is represented by a score of one, while "most or all time" is represented by a score of four. Due to the validity and reliability of the SAS scale, which has internal consistency and test-recovery reliability scores of 0.93 and 0.77, it is widely used in China.[17] A SAS score of 50 or higher indicates the presence of anxiety symptoms or the anxious state: mild anxiety is represented by scores between 50 and 59, moderate anxiety by scores between 60 and 69, and severe anxiety by scores of 70 or above.

Assessment of sleep quality

The Pittsburgh Sleep Quality Index (PSQI) is a widely used questionnaire in research and clinical practice for assessing sleep quality.[18] The Chinese version of the PSQI exhibits a high overall scale and test–retest reliability in China ($\alpha = 0.82$–0.83, $r = 0.77$–0.85).[19] This questionnaire is used to assess multiple dimensions of sleep status over a 1-month period. The PSQI is divided into seven components, including subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleeping medication, and daytime dysfunction. The sum of the seven component scores yields one global score of subjective sleep quality (range 0–21); higher scores represent poorer sleep quality.

Data analysis

The data were anonymized before conducting statistical analysis. The IBM SPSS program (version 26.0) was used for statistical analysis. Descriptive statistics, means, standard deviations (SDs), and scores for the self-report questionnaires are reported. Since all of the data were obtained from Likert-type scales, point-biserial correlation analysis was used for binary variables, and Pearson's correlation analysis was used for continuous variables.[20,21] When measurement data is transformed into classified data, some information is typically lost, which reduces the test effectiveness, therefore, no data has been transposed. The whole data was randomly split into the training set and test set with a ratio of 8:2. The training set was used for selecting potential factors by correlation analysis with THI as dependent variable and performed the hierarchical multiple linear regression. The test set is used to evaluate the generalization ability and the over-fitting error of the model. The threshold for statistical relevance was set at $P < 0.05$.

RESULTS

A total of 331 completed questionnaires from tinnitus patients were available for analysis. Among the participants, 184 were male, and 147 were female. Patients' ages ranged from 19 to 93 years, with an average of 54.86 ± 14.95 years. Additionally, 94% of the respondents were right-handed, compared to 6% of those who were left-handed. Furthermore, 116 were employed, while 215 were unemployed. The average BMI was 23.30 ± 2.85, with a range of 16.23–31.67. The results of audiological measurements and scale scores from questionnaires are displayed in Table 1.

Several preliminary tests were conducted to determine whether the hierarchical multiple linear regression model could be used for the research and to guarantee the validity of the data. First, the sample size of 331 was deemed adequate, given the number of predictive variables subjected to the test, according to the minimal sample size calculated theoretically. Second, to address the issue of multicollinearity, the regression analysis's tolerance must be greater than 0.1, while the variance inflation factor (VIF) must be less than 10. Only four factors—tinnitus frequency, tinnitus loudness, SAS scores, and PSQI scores—were found to be significantly associated with the dependent variables (THI scores) in the correlation analysis, as shown in Table 2. The remaining five factors were converted into control variables to avoid interference.

TABLE 1 Baseline information of patients with tinnitus ($n = 331$).

Characteristics	N	%	Min	Max	Mean	SD
Gender						
Male	184	55.6				
Female	147	44.4				
Handedness						
Right	311	94.0				
Left	20	6.0				
Employment status						
Employed	116	35.0				
Unemployed	215	65.0				
Age (years)			19	93	54.86	14.95
Body mass index (BMI)			16.23	31.67	23.30	2.85
Tinnitus frequency (Hz)			20	8000	2974.21	2654.65
Tinnitus loudness (dB HL)			2	100	47.94	19.10
SAS scores			24	68	43.99	6.45
PSQI scores			1	16	5.52	3.27
THI scores			2	98	28.60	18.00

Abbreviations: PSQI, Pittsburgh Sleep Quality Index; SAS, Self-rating Anxiety Scale; THI, Tinnitus Handicap Inventory.

TABLE 2 Correlation analysis between variables and THI scores.

Variables	P value	r	P
Gender	0.874		−0.010
Handedness	0.293		0.065
Employment status	0.862		−0.011
Age	0.314	−0.062	
BMI	0.163	0.865	
Tinnitus frequency	0.043*	0.124	
Tinnitus loudness	<0.001***	0.226	
SAS scores	<0.001***	0.548	
PSQI scores	<0.001***	0.413	

Abbreviations: BMI, body mass index; *P*, point-biserial correlation coefficient; PSQI, Pittsburgh Sleep Quality Index; r, Pearson's correlation coefficient; SAS, Self-rating Anxiety Scale.
$^*P < 0.05$; $^{***}P < 0.001$.

A two-stage hierarchical multiple linear regression model was conducted to examine the relationship between the set of independent variables (tinnitus frequency, tinnitus loudness, SAS scores, PSQI scores) against the dependent variable (THI scores) after controlling for the effects of gender, handedness, employment status, age, and BMI. From Table 3 (i.e., Model 1 with gender, age, BMI, employment status, handedness as predictors of THI scores), the R^2 (0.065) was significant ($F = 2.482$, $P = 0.033$), as it could account for 6.5% of the variance. It is clear that a positive relationship existed between the controlled variables and the dependent variable, though the relationship was weak. Model 2 adds four predictive variables (tinnitus frequency, tinnitus loudness, SAS scores, PSQI scores) on the basis of Model 1, escalated the R^2 value from 0.065 to 0.459, thus 45.9% of the variance had been accounted for. The R^2 change was also highly significant ($F = 16.407$, $P < 0.001$). These results clearly showed that the four predictive variables contributed significantly towards THI scores.

TABLE 3 Model summary of hierarchical multiple regression.

Model	R^2	Adjusted R^2	ΔR^2	F	P value
1	0.065	0.039	0.065	2.482	0.033*
2	0.459	0.431	0.394	16.407	<0.001***

Note: Predictors of Model 1: (Constant), Gender, Age, BMI, Employment status, Handedness; Predictors of Model 2: (Constant), Gender, Age, BMI, Employment status, Handedness, Tinnitus frequency, Tinnitus loudness, SAS scores, PSQI scores.
Abbreviations: *F*, value of the analysis of variance (ANOVA); R^2, coefficient of multiple determination.
$^*P < 0.05$; $^{***}P < 0.001$.

From Table 4, the coefficients for the constant and nine predictors of THI scores in Model 2 were as follows: Constant, $B = -51.797$, $t = -4.484$, $P < 0.001$: highly significant; Gender, $B = 0.322$, $t = 0.149$, $P = 0.882$: not significant; Age, $B = -0.158$, $t = -1.644$, $P = 0.102$: not significant; BMI, $B = 0.520$, $t = 1.413$, $P = 0.159$: not significant; Employment status, $B = -0.756$, $t = -0.249$, $P = 0.804$: not significant; Handedness, $B = 0.577$, $t = 0.155$, $P = 0.877$: not significant; Tinnitus frequency, $B = 0.000$, $t = 1.269$, $P = 0.206$: not significant; Tinnitus loudness, $B = 0.161$, $t = 2.604$, $P = 0.010$: significant; SAS scores, $B = 1.310$, $t = 7.685$, $P < 0.001$: highly significant; PSQI scores, $B = 1.680$, $t = 5.433$, $P < 0.001$: highly significant.

Based on the study above, the most accurate model for predicting severity in tinnitus patients would be the linear combination of the constant, tinnitus loudness, SAS scores, and PSQI scores

The Model:

$$Y(\text{THI scores}) = \beta_0 + \beta_1(\text{Tinnitus loudness}) + \beta_2(\text{SAS scores}) + \beta_3(\text{PSQI scores}),$$

where, β_0, β_1, β_2, and β_3 are −51.797, 0.161, 1.310, and 1.680, respectively.

DISCUSSION

Based on the available data, this regression model demonstrated that the severity of tinnitus was mainly positively correlated with three factors: tinnitus loudness, degree of anxiety, and sleep quality. Together, these factors accounted for 45.9% of the variance in the THI scores, which was consistent with homogeneous regression

TABLE 4 Summary of hierarchical linear regression analysis for variables predicting tinnitus severity.

Model	Variables	*B*	Beta	*t* value	*P* value	Tolerance	VIF
1	(Constant)	10.369		0.871	0.385		
	Gender	−2.696	−0.075	−0.982	0.327	0.893	1.120
	Age	−0.225	−0.185	−1.821	0.070	0.510	1.961
	BMI	1.097	0.179	2.342	0.020*	0.895	1.117
	Employment status	0.262	0.007	0.067	0.947	0.491	2.037
	Handedness	6.855	0.106	1.446	0.150	0.980	1.020
2	(Constant)	−51.797		−4.484	<0.001***		
	Gender	0.322	0.009	0.149	0.882	0.853	1.172
	Age	−0.158	−0.130	−1.644	0.102	0.495	2.018
	BMI	0.520	0.085	1.413	0.159	0.859	1.164
	Employment status	−0.756	−0.020	−0.249	0.804	0.478	2.094
	Handedness	0.577	0.009	0.155	0.877	0.942	1.061
	Tinnitus frequency	0.000	0.073	1.269	0.206	0.944	1.059
	Tinnitus loudness	0.161	0.154	2.604	0.010*	0.892	1.121
	SAS scores	1.310	0.450	7.685	<0.001***	0.908	1.102
	PSQI scores	1.680	0.315	5.433	<0.001***	0.923	1.084

Abbreviations: *B*, nonstandardized regression coefficient; Beta, standardized regression coefficient; BMI, body mass index; *t*, statistics; VIF, variance inflation factor.

*$P < 0.05$; ***$P < 0.001$.

analysis conducted in other countries; among patients seen in tinnitus clinics in the United Kingdom[22] and Germany,[23] these factors accounted for 44% and 30% of the variance, respectively. Among these three factors, the degree of anxiety and sleep quality had greater weight, while tinnitus loudness carried less weight.

Tinnitus can be characterized by dimensions such as pitch, loudness and the described type of sound and localization. Psychoacoustic measurements include pitch matching, loudness matching, with most researchers agreeing that loudness matching at 1 kHz yields the most reliable results.[24,25] Our results didn't find a connection with tinnitus frequency, but did reveal a slight yet significant positive correlation between the THI handicap level and tinnitus loudness. This conclusion was supported by a previous study.[26]

Tinnitus-related negative emotions can activate the limbic system's stress response, leading to increased sympathetic activity and dysfunction. These areas play a crucial role in the development of conditions like anxiety, which might indirectly affect a patient's psychological state.[27,28] Anxiety would heighten tinnitus sensitivity in patients, exacerbate subjective discomfort, lower tolerance, and frequently result in exaggerated tinnitus symptoms. The correlation analysis ($r = 0.548$) and regression analysis ($B = 1.310$) in this study both demonstrate a strong association between anxiety and tinnitus severity, as expected.

Patients with tinnitus often experience poorer sleep quality, and vice versa, insomnia and other sleep disorders can make tinnitus more distressing. Theoretical justification has been supplied by the significant association ($P < 0.001$) in the aforementioned univariate and multivariate analyses. A dose–response correlation between tinnitus severity and sleep quality was calculated. Tinnitus is typically associated with changes in the auditory pathway's spontaneous neuronal activity. Abnormal neural activities, such as increased auditory neuron spontaneous discharge rates or altered neural synchronization, may contribute to tinnitus. On the other hand, sympathetic nerve hyperactivity may also stimulate the prefrontal cortex and amygdala, increasing activity in regions involved in processing emotions and autonomous bodily function, thereby causing sleep disturbance.[29,30]

Our data contributes to the growing body of literature that positively correlates tinnitus severity with comorbid anxiety and sleep disturbance. There may be at least three potential links between anxiety, sleep disorder, and tinnitus: anxiety and sleep disorder affecting tinnitus; tinnitus predisposing to anxiety and sleep disorders; tinnitus appearing as a comorbidity in patients with anxiety and sleep disorder. Therefore, larger-scale studies focusing on causality are still needed.

Notably, the BMI, one of the Model 1 control variables, is statistically different from the others ($P = 0.020$, $B = 1.097$), while there was no statistical difference in the Model 2's analysis ($P = 0.159$, $B = 0.520$). The association between BMI and tinnitus has been widely noticed. Underweight women in a large-scale study involving 4628 premenopausal Korean women had a higher probability of developing tinnitus.[31] However, it was discovered that among Italian adults, obesity and tinnitus were causally linked.[32] The varying results in the correlation between BMI and tinnitus among research may result from different populations being recruited. Other demographic predictors were not included in the regression model, and although many studies have addressed the relationship between tinnitus occurrence and factors such as gender and age, they have focused more on incidence than severity. In addition, the Chinese population is predominantly right-handed (94% in this study). The study results do not establish a definite relationship between handedness and tinnitus severity, nor is there evidence for audiometric asymmetry and tinnitus laterality

Limitations

The cross-sectional design of the study, along with a relatively small sample size, limits the ability to establish causal links between tinnitus, sleep disturbance, and anxiety. A more comprehensive longitudinal investigation is required to ascertain the psychological profile and influencing mechanisms of Chinese tinnitus sufferers. In addition, the structured close-ended questionnaire relies on self-reporting to assess individual's perception of their disorders' severity. Patients may occasionally score higher than their actual condition due to the desire for more medical attention. Given that respondents provide subjective feedback on their symptom severity, the data set's ability to objectively quantify is limited. Future studies should incorporate both objective and subjective measurements to minimize confounding factors and enhance data reliability. Lastly, the random data representing 20% of the data set was utilized as the test set for testing to assess the generalization capability of the model and rule out over-fitting mistakes. Due to the limitation of the sample size of the test set, the generalization of the model has not been effectively tested. Future studies should expand the sample size to evaluate the model's generalizability among tinnitus patients and the general population.

CONCLUSIONS

The purpose of this article was to explore predictors of tinnitus severity through a retrospective data analysis. At the onset, we set out to use the hierarchical multiple regression model to examine the relationship between a set of nine independent variables (Gender, Handedness, Employment status, Age, BMI, Tinnitus frequency, Tinnitus loudness, SAS scores, and PSQI scores) and a dependent variable (THI scores) to identify the predictors which have significant influence on the severity of tinnitus. After correlation analysis to eliminate the interference of control variables, it was determined that the best-fitting model for predicting tinnitus severity included a linear combination of the constant factor, tinnitus loudness, SAS scores, and PSQI scores.

On account of the above revelation, the severity of tinnitus symptoms (measured using the THI) is positively correlated with one's tinnitus loudness, degree of anxiety, and sleep quality. Screening for symptoms of anxiety and sleep disturbance may help identify those at risk of experiencing tinnitus, or experiencing adverse effects of tinnitus. In turn, this would enable effective targeting of interventions and support. Early identification and attention to these psychosomatic factors may minimize the effect of tinnitus on quality of life and help patients develop coping skills that reduce the influence of the condition. It is crucial to promptly recognize and address these comorbidities and related factors for optimal management of patients with tinnitus.

AUTHOR CONTRIBUTIONS

Yue Deng and Huan-Hai Liu designed the experiment and won approval from the ethics committee. Teng-Fei Li wrote the main manuscript text and prepared the tables, supervised primarily by Feng-Zhen Li and Sheng-Lei Wang, with Cai-Quan Liang and Hu Peng as secondary supervisors. Xu-Dong Cha and Tian-Yu Wang analyzed the results, edited it into sub-headings, added data to the tables, and added references to the manuscript. Wen-Wen Ren critiqued, edited, and rearranged the entire manuscript. All authors reviewed the manuscript. Teng-Fei Li, Xu-Dong Cha and Tian-Yu Wang have contributed equally to this work and share the first authorship.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

All data generated or analyzed during this study are included in the additional files for review. Detailed raw data files are available from the corresponding author on reasonable request.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Medical Ethics Committee of the Shanghai Changzheng Hospital (Study on the occurrence and treatment of mental disorders in tinnitus patients, 2018SLYS1). The patients/participants signed and provided their written informed consent to participate in this study.

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