AUDIOLOGY • 청능재활 REVIEW PAPER
2012;8:137-148
ISSN 1738-9399

이명에 대한 심리적 측정과 심리음향학적 측정

대구가톨릭대학교 언어청각치료학과 • 생체모방감각제어연구소 • 가톨릭 청각음성언어센터

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ABSTRACT

Psychometric and Psychoacoustic Measures of Tinnitus

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Tinnitus is a ringing in the ears without external sounds from outside. Tinnitus is not a disease but a symptom affecting the quality of life in daily lives. Although many different measures of tinnitus have been developed, it is not easy for clinician to select one or some of these measures to fit the goals of the management of tinnitus. Therefore, the objective of this study is to review a variety of previous studies of tinnitus in terms of psychometric and psychoacoustic measures of tinnitus to provide clinically useful and valuable information to professionals who want to develop a standardized test of tinnitus. This study reviewed a variety of literatures associated with the psychometric measures including tinnitus handicap inventory, tinnitus questionnaire, tinnitus reaction questionnaire, tinnitus handicap questionnaire, tinnitus cognition questionnaire, and tinnitus disability index. The psychoacoustic measures of tinnitus including pitch, loudness, masking, and residual inhibition were thoroughly reviewed. Finally, we investigated whether there is a relationship between the psychometric and psychoacoustic measures of tinnitus. However, the psychometric measures were not clearly and directly related to the psychoacoustic measures. This indicates that they do not test the same attributes or constructs of tinnitus. In addition, this may result from the different natures of tinnitus, different mechanisms and sites of action, and high variability between and within subjects. Although there are considerable disagreements in the measures of tinnitus, this paper will provide clinically useful and meaningful information for developing a standardized test of tinnitus.

KEY WORDS : Tinnitus, Psychometric measures, Psychoacoustic measures, Tinnitus Handicap Inventory (THI), Tinnitus Questionnaire (TQ), Tinnitus Reaction Questionnaire (TRQ), Tinnitus Handicap Questionnaire (THQ), Tinnitus Cognition Questionnaire (TCQ), Tinnitus Disability Index (TDI), Pitch match, Loudness match, Mask of tinnitus, Residual inhibition

INTRODUCTION

Hearing loss is one of the common disorders affecting human's communication in daily lives. Approximately, nearly 17 children in 1,000 under 18 years of age and 17 percent (36 millions) of American adults have some degree of hearing loss. In addition, one third of Americans 65 to 74 years old and 47 percent of those 74 and older have hearing loss. Most of people with hearing loss may experience tinnitus. One third of all adults experience tinnitus at some time in their lives. About 10-15% of adults (22.7 million) have experienced tinnitus for brief period (more than three months) (Coles, 1984; McFadden, 1982). There was a prevalence rate of 10.9% in tinnitus in Korean population (Koo et al., 1999).

Generally, tinnitus refers to a ringing in the ears including roaring, clicking, hissing, whistling, pulsing, chirping, whooshing, or buzzing when no sound from outside is presented to the ears. Tinnitus may be soft or loud, high or low pitched, and occurred in either one or both ears. There

논문접수일 : 2012년 10월 08일
게재확정일 : 2012년 12월 11일
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are two different types of tinnitus: objective and subjective tinnitus (Lanting et al., 2009). Objective tinnitus is one that examiner can hear when clients take a tinnitus test. Objective tinnitus is rare and has been reported only in small cases. Subjective tinnitus refers to tinnitus only individual can hear. This is the most common type of tinnitus. Tinnitus is not disease but a symptom which indicates there is a problem in the auditory system including the inner ear and the brain. Tinnitus can affect quality of life although there is a significant difference among people. People with tinnitus may experience other complications such as fatigue, stress, sleep problems, trouble concentrating, memory problems, depression, and anxiety and irritability. Tinnitus and its complications can result from a number of health conditions such as hearing loss, Meniere's disease, ear infection, noise exposure, blast overpressure, head injury, ototoxic drugs, anemia, hypertension, stress, smoking, hormonal changes in women, and thyroid abnormalities (Choi, 2012).

Although it has been known that there are different measures of tinnitus, it is not easy for clinician to select one or some of many measures of tinnitus and to plan its management. The most important factor in the success of the evaluation and management of tinnitus is clinician's ability to perform the tinnitus measurement, interpret the results, and plan the management. In measurement of tinnitus, there is no a fixed or standardized test protocol which clinicians should follow to obtain a reliable, valid, and clinically useful data. Therefore, the success of the tinnitus measurement depends on clinical judgment by an experienced clinician. For successful measurement and management of tinnitus, the skilled clinician should develop a clear understanding of the various measures of tinnitus.

There is no cure for tinnitus, but management and treatment which help many people deal better with tinnitus are now available. These depend on the good evaluation of tinnitus. There are two different measures of tinnitus: psychometric and psychoacoustic measures. Psychometric measures (subjective evaluation) include various survey including tinnitus handicap inventory, tinnitus questionnaire, tinnitus reaction questionnaire, tinnitus handicap questionnaire, tinnitus cognition questionnaire, and tinnitus disability index. Psychoacoustic measures include various tests including pitch, loudness, masking, and residual inhibition. Physiological tests include distortion product otoacoustic emission (DPOAE), auditory middle latency responses (AMLR), functional magnetic resonance imaging (fMRI) and positron emission tomography (PET). These physiological tests were not included in this study. This paper aims to review a variety of previous studies of tinnitus in terms of the psychometric and psychoacoustic measures of tinnitus and to investigate how psychometric measures relate to psychoacoustic measures of tinnitus. This will provide clinically useful and valuable information to undergraduate students, graduate students, and professional clinicians who want to develop reliable and valid tests of tinnitus.

MATERIALS AND METHODS

1. Psychometric Measures of Tinnitus: Subjective Evaluation

1-1. Tinnitus Handicap Inventory (THI)

Tinnitus handicap inventory (THI) was developed to provide a self-report tinnitus handicap measure that is brief, easy to administer and interpret, broad in scope, and psychometrically robust (Newman et al., 1996). After designed to quantify the impact of tinnitus on daily living, THI has been widely used in many clinical practices in various countries and as a useful tool for tinnitus measurement (Kim et al., 2002; Lim et al., 2010). THI is a self-administered 25 item questionnaire scored on a 3-point scale in three subscales: emotional, functional, and catastroptic subscales. The emotional subscale is composed of nine questions relating to anger, frustration, irritability, anxiety, depression, and insecurity while the functional subscale consists of eleven questions of stress, loss of concentration and sleep, interference with job, household responsibilities, and social activities. Finally, the catastrophic subscale contains five questions of desperation, perception of having a terrible disease, lack of control, and inability to escape and cope. The total THI score can be obtained by the sum of the scores for all three subscales and grouped into four categories indicating handicap severity: no handicap (0-16), mild handicap (18-36), moderate handicap (38-56), and severe handicap (58-100). It was reported that the total scale possessed excellent internal consistency reliability. There were no significant differences in age and gender (Newman et al., 1996). There were weak correlations between the THI and the Beck Depression Inventory, Modified Somatic Perception Questionnaire, pitch and loudness judgments and significant correlations between the THI and the symptom rate scales (Newman et al., 1996).

1-2. Tinnitus Questionnaire (TQ)

The TQ known simply as the Tinnitus Effect Questionnaire (TEQ) was developed to measure various dimensions of tinnitus complaints (Hallam, 1996). The TQ consists of 52 items describing commonly reported complaints of tinnitus on a 3-point scale (true, partially true, and not true) in terms of three subscales including emotional stress, intrusiveness, sensory and perceptual difficulties, and sleep difficulties. The presence of complaint is measured by positive responses except six items (1, 7, 32, 40, 44, and 49) expressed by negative words. The results were reported in a range of 0-104 by assigning a value of 0-2 on each item (Henry & Wilson, 1995, 1998). The TQ possessed high internal consistency with item-total correlations ranging from 0.41 to 0.77 (Hallam, 1996; Henry & Wilson, 1998).

1-3. Tinnitus Reaction Questionnaire (TRQ)

The TRQ was developed to assess the psychological distress associated with tinnitus (Wilson et al., 1991). The TRQ is composed of 26 items on a 5-point scale in terms of psychological stress associated with tinnitus such as general stress, interference, severity, and avoidance. All items are scored in the same direction. In this test, subjects were asked to indicate the extent to which each of the possible efforts has applied to them over the last week (Henry & Wilson, 1998). The results were reported in a range of 0-104 (Henry & Wilson, 1995, 1998). The TRQ showed a good test-retest reliability and internal consistency. There were high correlations between the TRQ and clinician ratings and self-report measures of anxiety and depression (Wilson et al., 1991).

1-4. Tinnitus Handicap Questionnaire (THQ)

The THQ was developed to assess the psychometric properties of tinnitus (Kuk et al., 1990). The THQ consists of 28 items describing potential effects of tinnitus on hearing, lifestyle, health, and emotional status. All the items were expressed in negative words except two items of 26 and 27. Subjects were asked to assign a number between 0 and 100 based on the extent to which they agree with each item (Henry & Wilson, 1998). The total score was expressed by a mean score ranging from 0 to 100. The THQ showed high internal consistency, reliability, and validity. This had good correlations with life satisfaction and depression scale (Kuk et al., 1990). In addition, this questionnaire could be used to compare a patient's tinnitus handicap with the norm, identify specific areas of handicaps, and monitor a patient's progress with particular treatment programs (Kuk et al., 1990).

1-5. Tinnitus Cognition Questionnaire (TCQ)

The TCQ was developed to assess the kinds of cognitions that people might think of tinnitus (Wilson & Henry, 1998). The TCQ consists of 26 items containing two subscales: a set of 13 negative items and another set of 13 positive items. Subjects were asked to indicate how often they have been aware of thinking a particular thought on occasions when they noticed their tinnitus on a 5-point scale ranging from never to very frequently. The total score of the TCQ ranged from 0 to 104 indicating that a high score represents high engagement in negative cognitions and low engagement in positive cognition associated with tinnitus (Henry & Wilson, 1995). The TCQ showed good test-retest reliability and high internal consistency (Henry & Wilson, 1995, 1998).

1-6. Tinnitus Disability Index (TDI)

The TDI was developed as a self-report measure for disability due to tinnitus on daily life activities (Cima et al., 2011). The TDI consists of 7 items corresponding to seven major aspects of daily life: family/home responsibilities, recreation, social activity, occupation, sexual behavior, self-care, life-support activity. Each of these seven subscales was scored on a horizontal numerical scale (0-10): zero represents no disability while ten indicates total disability. The TDI is very concise, easy to administer and interpret, and valid and reliable to represent a problematic factor in an individual's daily life. The TDI showed high test-retest reliability and internal consistency. There were high correlations between the

Table 1. Comparative Analysis of Psychometric Measures of Tinnitus

Psychometric Measures	Validity/ Reliability	Items	Scales	Subscales
Tinnitus Handicap Inventroy (THI)	+/+	25	0-never 2-sometimes 4-yes	Functional Emotional Catastrophic responses
Tinnitus Questionnaire (TQ)	+/+	52	True Partly true Not true	Emotional stress Cognitive stress Intrusiveness Auditory-perceptional difficulties Sleep disturbance Somatic complaints
Tinnitus Reaction Questionnaire (TRQ)	+/+	26	0-Not at all 4-Almost	General stress Interference Severity, Avoidance
Tinnitus Handicap Questionnaire (THQ)	+/+	27	0-Strongly disagree 100-Strongly agree	Physical health Emotional status Social consequences Hearing/communications Personal viewpoint
Tinnitus Cognition Questionnaire (TSQ)	+/+	26	0-Never 4-Very frequently	Negative Positive
Tinnitus Disability Index (TDI)	+/+		0-No disability 10-Total disability	Family/Home Responsibility Recreation Social Activity Occupation Sexual behavior Self-care Life support activity

TDI and subjective ratings of tinnitus intensity but negative correlations between the TDI and quality of life ratings and distress due to tinnitus (Cima et al., 2011).

The psychometric measures of tinnitus mentioned above can summarized for comparative analysis among the psychometric measures in terms of validity/reliability, numbers of items, scales, and subscales. Table 1 represents comparative analysis of the psychometric measures of tinnitus. Based on the subscales of the psychometric measures, the most common factors of the psychometric measures of tinnitus are listed (Table 2). These factors provide an excellent insight and a comprehensive picture about various difficulties that people with tinnitus can encounter in their daily lives.

2. Psychoacoustic Measures of Tinnitus: Audiological Evaluation

In 1982, the Committee on Hearing, Bioacoustics, and Biomechanics of the National Research Council in the National Academy of Sciences reported “Tinnitus-Facts, Theories and Treatment”. The main goal of this committee was to develop standardized test procedures of tinnitus. Therefore, the committee developed general guidelines for the clinical evaluation of tinnitus. They can be summarized into four different measures of tinnitus: pitch, loudness, masking, and residual inhibition (McFadden, 1982). These measures were accomplished by a matching procedure. In the matching procedure, a signal was presented to the ear opposite the side where the tinnitus was being measured and

Table 2. Common Factors of Psychometric Measures of Tinnitus

Common Factors of Psychometric Measures
Emotional problems
Social problems
Intrusiveness
Communication(Hearing) difficulties resulting from tinnitus
Sleep disturbance
Cognitive interference
Reduced quality of life due to tinnitus
Recreation interference by tinnitus
Interference with rest and relaxation
Somatic complaints or reduced physical activity attributed to tinnitus
Work interference by tinnitus
Reduced self control due to tinnitus

patients were asked to match the pitch of the tinnitus (Schleuning & Johnson, 1997). The signals were increased until the patients indicate that it is equally loud to their tinnitus. The tinnitus loudness refers to the difference between the hearing threshold and the loudness level. The effectiveness of noise to mask the tinnitus was determined by minimum masking level indicating the difference between the threshold level for the noise and the amount of noise required to mask the tinnitus. Finally, the residual inhibition indicates how the tinnitus can be inhibited by exposure to the masking sound (Schleuning & Johnson, 1997).

2-1. Pitch Match of Tinnitus

The pitch match of tinnitus is to find out the spectral characteristics of tinnitus with pure-tone audiometer: high pitched or low pitched. Pitch is the psychological concept indicating the frequency of the sound (Lass & Woodford, 2007). The pitch match method is to identify the frequency characteristics of tinnitus, to present a specified bandwidth of noise centered at a specific frequency of tinnitus, and to match the pitch of tinnitus for masking. Therefore, this has been called a method to describe “the frequency matching the pitch of the tinnitus”, “the frequency matching the tinnitus”, or “the tinnitus frequency”.

The pitch match of tinnitus is typically related with the audiometric configuration obtained from pure-tone audiometer. The pure-tone audiometric measurement has been widely performed for three important factors describing the characteristics of tinnitus: (1) determining its frequency, (2) determining its intensity, and (3) level of masking of tinnitus (Meikle & Walsh, 1984). Generally, the pitch of tinnitus is directly associated with high-frequency hearing loss at or above 3,000 Hz (Meikle et al., 1995). High-frequency hearing loss is the most common audiometric configuration shown in the tinnitus clinic (Meikle et al., 1995). However, there is low probability for the pitch of tinnitus related with low frequency hearing loss below 1,000 Hz (Meikle & Walsh, 1984; Meikle et al., 1995). Many studies showed that the pitch of tinnitus tended to correspond to the frequency regions of significant hearing loss and inversely related to the degree of hearing loss (Meikle & Walsh, 1984; Meikle et al., 1995; Henry & Meikle, 2000).

Several psychophysical methods including adjustment, limits, and adaptation were used for matching the pitch of tinnitus (Tyler & Conrad-Armes, 1983). The adaptation and adjustment methods of them were recommended to obtain a single pitch match by presenting matching tones in the ipsilateral ear to avoid problems with binaural diplacusis (differences in pitch percept between ears). Although the pitch of tinnitus seems to be one of the easiest tasks for individuals with tinnitus, inexperienced individuals tend to confuse pitch and loudness and pitch and octave above and below the best pitch match of tinnitus. For pitch matching, a two-alternative forced-choice procedure using discrete pairs of frequencies separated by 1,000 Hz was used to reduce confusion between pitch and loudness (Vernon & Fenwick, 1984) and a forced-choice double-staircase procedure using 100 Hz step sizes was used to obtain the frequency of tinnitus (Penner & Bilger, 1992). The Committee on Hearing, Bioacoustics, and Biomechanics of the National Research Council in the National Academy of Sciences recommended the pitch matching method at the contralateral ear in unilateral tinnitus (McFadden, 1982). An unusual method using a novel testing device called "a heptachord generator" was used to obtain an accurate tinnitus pitch match by presenting tones according to the standard musical scale (do-re-mi) (Ohsaki et al., 1990). The heptatonic method was more accurate than a conventional audiometer. Recently, it was reported that the frequency of tinnitus determined by a high frequency audiometer was greater than that determined by conventional audiometer. The higher the frequency of tinnitus, the more discomfort the patient manifests (Lopez-Gonzalez et al., 2012). Although many different methods mentioned above have been recommended for pitch matching of tinnitus, there is great variability in pitch matching of tinnitus. This indicates the possibility of different mechanisms and origins which are responsible for pitch matching of tinnitus.

2-2. Loudness Match of Tinnitus

Loudness is a subjective term indicating how people perceive the intensity of sound. Typically, it has been reported that tinnitus was matched to tones only a few decibels above threshold (Vernon, 1977). However, individuals with tinnitus may experience recruitment. Recruitment refers to a large increase in the perceived loudness of a signal produced by relatively small increases in intensity above threshold. Recruitment is one of possible causes of the small loudness matches of tinnitus. The size of the loudness match decreases as a function of frequency (Vernon, 1977). The effect of recruitment may be evaluated by matching the loudness of tinnitus at both tinnitus frequency and normal hearing frequency (Goodwin & Johnson, 1980). The loudness match of tinnitus [24 dB SL(sensation level)] at normal hearing frequency is higher than that measured at the tinnitus frequency (7 dB SL). The loudness recruitment at the tinnitus frequency is not appropriate because it can be underestimated (Goodwin & Johnson, 1980). Another study reported that the slopes of loudness growth at the tinnitus frequency are steeper than a normal hearing frequency of 1 kHz (Penner, 1986). This indicates that loudness growth is more rapid at the tinnitus frequency than at 1 kHz. In another study, the loudness matches obtained at 1 kHz were relatively highly correlated with the tinnitus severity and sensitive to changes in loudness produced by furosemide (Risey et al., 1989). It has been reported that there are two types of loudness matching of tinnitus: congruent and convergent (Mitchell et al., 1993). Congruent matching indicates that the loudness is parallel with the hearing threshold while convergent matching represents that the loudness converges upon the hearing threshold in the high frequencies.

To overcome the discrepancy between the loudness matches obtained at the tinnitus frequency and at normal hearing frequency, a new method transforming the loudness matches from dB SL to sones was proposed (Tyler & Conrad-Armes, 1983). These authors thought that sones can be the more appropriate way to represent tinnitus loudness. However, another study pointed out that 1 sone in loudness may be perceived a different loudness levels by different individuals (Hinchcliffe & Chambers, 1983). This indicates that there are considerable individual differences in loudness growth and in loudness acceptability. Therefore, these authors suggested "personal loudness unit (PLU)" as the comparison standard for subjective magnitude estimation. In addition, other expressions of loudness measurement in dB SL and dB HL (hearing level) were proposed but poorly correlated with psychological scales of tinnitus severity (Hallam et al., 1985). Another method correcting the underestimated loudness matches of tinnitus, an "averaged loudness function" was developed but not widely used because it was very difficult to determine an averaged loudness abnormality (Matsuhira et al., 1992). The Alterating Binaural Loudness Balance (ABLB) technique was developed to evaluate loudness growth in unilateral tinnitus in the contralateral ear (Henry, 1996). A lot of percent of the variance in this study remain unexplained.

Although many different methods have been developed for loudness matching of tinnitus, there are great variability and unreliability in loudness matching of tinnitus. This may indicates the presence of different mechanisms and origins resulting in loudness matching of tinnitus.

2-3. Masking of Tinnitus

Generally, masking is a process in which the threshold of a signal is raised by the existence of another signal (masker). Therefore, masking represents the difference in decibels between hearing thresholds with and without masker (Lass & Woodford, 2007). Although there are clear similarities between general masking and masking of tinnitus, the law of general masking may not correspond to the masking of tinnitus. The general masking is based on mechanical interaction of signal and masker while the masking of tinnitus depends on neural inhibition (Feldmann, 1983; Mitchell et al., 1993). It indicates that the masking of tinnitus may involve both masking and neural interaction.

The characteristics of the tinnitus masking may involve frequency dependence, adaptation, and diotic effects (Henry & Meikle, 2000). The frequency dependence of the tinnitus masking is categorically different from the conventional tonal masking (Mitchell, 1983). In the frequency dependence of the tinnitus masking, there were four different types: convergent, congruent, distant, and persistent. The convergent type indicates when the tinnitus masking frequency and auditory thresholds converged only at some frequencies. The congruent type refers to when the tinnitus masking frequency and auditory thresholds converged only at most frequencies while distant types show only a weak trend. Generally, the concept of critical bands applies to the general masking. The closer the frequency of the masker is to the frequency of the signal, the more effectively it masks the signal (Lass & Woodford, 2007). In general masking, the width of the masker has been an important factor affecting the success of the masking. However, the width of the masker is not important factor affecting the effectiveness of the tinnitus masking (Johnson & Mitchell, 1984). The abnormal masking patterns shown in the tinnitus masking may indicate the reduced frequency resolution related with hearing loss (Tyler & Conrad-Armes, 1984).

There was a possible adaptation phenomenon in tinnitus masking. After investigating the neural adaptation of broadband noise and an external tone masked by the noise, the neural mechanism of the tinnitus was different from that of the tone (Penner et al., 1981). Adjusting the intensity of a pulsed tone to remain at the same loudness as the tinnitus, the intensity of the pulsed tone presented ipsilaterally was greater than one presented contralaterally (Penner, 1988). Tracking the intensity of a pure tone required to maintain constant loudness, there was a controversy between stimulus changes required to maintain loudness and changes needed to maintain masking (Penner & Bilger, 1989). Some cases showed agreement but other cases represented disagreement.

Finally, how to present noise to both ears is another important factor affecting the mask of tinnitus. Diotical presentation of the masking noise was compared to the dichotical presentation (Henry & Meikle, 2000; Johnson & Hughes, 1992). Diotical presentation refers to delivering the same noise signal to both ears while dichotical presentation indicates delivering the different noise signals with identical spectral characteristics to the two ears. The levels of noise required to maintain effective masking was significantly greater for the diotical presentation than for the dichotical one (Johnson & Hughes, 1992). The diotical effect of the tinnitus masking corresponds to the known information of masking level differences.

2-4. Residual Inhibition of Tinnitus

Residual inhibition is a phenomenon which a tinnitus is temporarily reduced after the presentation of masking noise for short period of time (Feldman, 1971). Residual inhibition is a fundamental aspect of tinnitus masking phenomenon indicating post-masking suppression (Henry & Meikle, 2000; Tyler & Conrad-Armes, 1984). The post-masking suppression may be occurred from a short of period (a few seconds or minutes) to long periods (several days) of time (Schleuning & Johnson, 1997). It has been reported that residual inhibition may be affected by several factor including the psychoacoustic properties of tinnitus, the characteristics of making noise, and hearing loss (Henry & Meikle, 2000). Another study described residual inhibition functions relating residual inhibition to the psychoacoustic properties of tinnitus and to the properties of making stimuli using computerized tools (Roberts et al., 2008).

The residual inhibition increases as the masking signals correspond to the frequency spectrum and bandwidth of the tinnitus (Roberts et al., 2008) and as the level of the masker rises above the level needed to mask the tinnitus (Feldmann, 1971, 1983; Vernon & Fenwick, 1984). In addition, the residual inhibition increases when the duration of masking becomes longer (Bailey, 1979; Tyler et al., 1984). There was a considerable correspondence between the residual inhibition function and the psychoacoustic properties of tinnitus. The residual inhibition function increases first at the audiometric edge and continues to rise with the depth of hearing loss to the limit of hearing (Roberts et al., 2008).

It is noteworthy that although many studies of residual inhibition showed consistent results, there is considerable variability of residual inhibition measures. This may result from differences in tinnitus measures, masking sounds, and masking procedures and within or between subject variability.

RESULTS

Based on psychometric and psychoacoustic measures of tinnitus reviewed above, clinicians can look for how the psychometric measures relate to the psychoacoustic measure of tinnitus. The relationship between psychometric measures and psychoacoustic measures of tinnitus remains unclear due to the conflicting evidences. It has been reported that there is no clear correlations between psychometric measures and psychoacoustic measures. Psychoacoustic measurements of tinnitus were not related to subjective descriptions of tinnitus (Graham & Newby, 1962). Any significant correlations between psychoacoustic measures (pitch, loudness, maskability) and subjective ratings of tinnitus severity were not found (Meikle et al., 1984). No relationship between tinnitus tests and subjective complaints in tinnitus were found (Hallam et al., 1984, 1985; Jakes et al., 1985; Hazell et al., 1985). No relationship was found between psychological stress and psychoacoustic measures of tinnitus (Henry & Wilson, 1995). In addition, any significant differences in various psychoacoustic measures of tinnitus were not found between those who had previously sought professional help and those who had not (Dineen et al., 1997). However, there were direct correlations between loudness matches at 1 kHz and tinnitus severity ratings but no correlations between tinnitus frequency and tinnitus severity ratings (Risey et al., 1989). High correlations between the subjective loudness ratings and the degree of tinnitus handicap and a low correlation between the loudness matches and tinnitus handicap were found (Kuk et al., 1990). Another study showed that the most severely distressed individuals experienced louder tinnitus as measured by a loudness match procedure (Henry & Wilson, 1995). The lack of unity between psychometric measures and psychoacoustic measures of tinnitus may suggest that they do not test the same attributes or constructs of tinnitus. In addition, the psychometric measures (subjective evaluation) and psychoacoustic measures (audiological evaluation) may result from different mechanisms and site of action.

DISCUSSIONS AND CONCLUSIONS

The objective of this paper was to review a variety of previous studies in terms of psychometric (subjective evaluation) and psychoacoustic measures (audiological evaluation) of tinnitus. This paper can provide clinically useful information of various psychometric and psychoacoustic measures of tinnitus and the management plan. In addition, we investigated whether there is a correlation between psychometric and psychoacoustic measures of tinnitus. There are considerable disagreements about this issue. This may result from several factors. One of them is associated with the nature of tinnitus. Generally, tinnitus is classified into objective and subjective tinnitus (Lanting et al., 2009). Objective tinnitus is one that can be heard by other people. This is rare and has been reported only in some cases. Objective tinnitus results from vascular anomalies near the middle or inner ear and involuntary contraction of muscles in the middle ear or in palatal tissue (Fox & Baer, 1991; Chandler, 1983; Howsam et al., 2005; Lanting et al., 2009). Various causes of objective tinnitus are listed in Table 3 (Seidman & Jacobson, 1996).

Table 3. Various Causes of Objective Tinnitus

Various Causes of Objective Tinnitus
Middle Ear neoplasms
Hypertension
Arteriosclerosis
Aneurysms
Vascular loops
Multiple sclerosis
Palatal myocionus
Temporomandibular joint disorders
Cervical spine problems
Benign intracranial hypertension
Palatal myoclonus
Middle ear muscle myoclonus

However, subjective tinnitus is far more common than objective tinnitus and has no acoustic stimulation. Subjective tinnitus results from sensorineural hearing loss, abnormal cellular mechanisms in neurons of the central auditory system, or aberrant input from the cochlea or non-auditory structures (Eggermont & Roberts, 2004; Lanting et al., 2009). Various causes of subjective tinnitus are listed in Table 4 (Seidman & Jacobson, 1996). The circumstances that direct differences between the objective and subjective tinnitus have not been provided make clinicians more confusing but more challenging for developing new methods.

Second factor explaining the disagreement is related to different mechanisms underlying tinnitus generation. Based on previous neuroimaging experiments on tinnitus, the characteristics of tinnitus may be different due to differences in neural activity as an attribute of tinnitus, somatosensory modulation, gaze-evoked activity, lidocaine as modulator of tinnitus, and steady state metabolic activity in cortical areas (Lanting et al., 2009). In sound-evoked neural activity as an attribute of tinnitus, tinnitus corresponds to abnormally small neural activity in the inferior colliculus (Melcher et al.,

Table 4. Various Causes of Subjective Tinnitus

Different Categories of Causes	Detail Contents of Causes
Common	Noise-Induced Hearing Loss Aging-Induced Hearing Loss Earwax blockage Ear bone changes (otosclerosis)
Congenital	Atresia Genetic Disorders
Neoplastic (Benign)	External Ear Canal: Osteoma & Exostosis Middle Ear: Cholesteatoma, Glomus tumor, Facial nerve neuroma, Hemangioma Inner Ear: Vestibular schwannoma, Cholesteatoma, Meningioma, Facial nerve neuroma
Neoplastic (Malignant)	External Ear Canal: Squamous cell carcinoma, Basal cell carcinoma Middle Ear: Carcinoma Central nerve system neoplasms
Vacular	Arteriovenous malformation Dhiscent jugular bulb Eagles's syndrome, Aneurysms Hypertension, Arteriosclerosis Vascular loop sysndrome Diabetes mellitus, Persistent stapedial artery
Neurologic	Palatal myoclonus, Seizure disorder Stapedial muscle spasm Tensor tympani muscle spasm Multiple sclerosis, Migraine Benign intracranial hypertension
Traumatic	External auditory canal trauma Tympanic membrane perforation Ossicular discontinuity, Head trauma
Miscellaneous	Noise, Meniere's disease, Presbycusis Perilymphatic fistula, Anemia, Ossicular fixation, Hyperthyroidism Patulous Eustachian tube, Page disease Hyperlipidemia, Otosclerosis Nutritional deficiencies Hypopigmentation Temporomandibular joint disorders

2000) and increased sound-evoked neural responses (Lanting et al., 2009). Somatosensory modulation of tinnitus includes forceful head and neck muscle contraction and oral-facial movement like jaw clenching of jaw protrusion (Levine et al., 2003; Chole & Parker, 1992). In gaze-evoked tinnitus, the properties of tinnitus can be changed by rapidly changing gaze or lateral gaze (Lanting et al., 2009). Lidocaine is a local anesthetic and anti-arrhythmic agent and has both central and peripheral sites of action affecting various molecular channels and receptors in the auditory system (Darlington & Smith, 2007; Trellakis et al., 2007). Using radioactive labeled glucose, steady state metabolic activity in cortical areas can be assessed. There is an asymmetric glucose metabolism in the auditory cortex activity in subjects with tinnitus (Wang et al., 2001).

Third factor explaining the disagreement is related to high variability in subjects with tinnitus. Although many different methods have been developed for psychometric and psychoacoustic measures of tinnitus, there are great variability and unreliability in psychometric and psychoacoustic measures of tinnitus. This may result from between subject variability. In addition, the psychometric measures may be essentially different from the psychoacoustic measures of tinnitus because they do not test the same attributes or constructs of tinnitus.

Finally, due to the limited pages of this paper, we could not deal with other physiological tests including distortion product otoacoustic emission (DPOAE), auditory middle latency responses (AMLR), functional magnetic resonance imaging (fMRI), and positron emission tomography (PET). Another study in future will investigate whether there are objective and physiologic measures of tinnitus, which may be a key in understanding the pathophysiology of tinnitus.

Acknowledgments

This study was in part supported by the Catholic University of Daegu.

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