

Review articles

Recording of tinnitus psychoacoustic measurements: an integrative literature review

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ABSTRACT

Purpose: to review both the national and international literature as well as to describe the methods used to collect psychoacoustic measurements in tinnitus patients.

Methods: the current integrative review was conducted on articles in specialized national and international journals, in both the Portuguese and English languages, available in the PubMed/Medline, BVS - LILACS and SCIELO databases. The following keywords and descriptors were used: hearing, tinnitus, psychoacoustic measurements, acuphenometry, and assessment, in both the Portuguese and English languages. The retrieved articles were read and selected for the review according to the eligibility criteria, which included the use of psychoacoustic measurements in tinnitus patients and the presence of a detailed methodological description of the protocol employed, in individuals with normal hearing and those with hearing loss.

Results: a total of 12 articles, in which psychoacoustic measures were used for the characterization and the measurement of tinnitus in individuals with normal hearing and in those with hearing loss, were reviewed. The main findings were associated with the sample characterization and the way in which the psychoacoustic measures were performed.

Conclusion: given the grouping of several protocols for tinnitus evaluation, which were determined following an integrative literature review, a great heterogeneity in the methods used to perform psychoacoustic measurements for tinnitus assessment for both clinical and scientific purposes was noted.

Keywords: Hearing; Tinnitus; Hearing Loss; Psychoacoustics

INTRODUCTION

Tinnitus has been previously described in the scientific literature as the perception of sound in the absence of an external environmental source^{1,2}. More precisely, such a symptom may originate from an injury occurring at any point of the auditory pathway (i.e. outer ear, middle ear, inner ear, auditory nerve, cochlear nucleus, inferior colliculus, and/or the central nervous system)³. The literature⁴ reports that hearing loss, even when temporary, may cause an increase in the sensitivity of the neurons of the subcortical auditory centers, resulting in tinnitus.

While tinnitus may be present in individuals with normal hearing, the perception of such a symptom may vary in location, i.e. either in the ears or in the head⁵.

Although tinnitus is a well-recognized hearing impairment, a method considered as the “gold standard” for its characterization and measurement is yet to be defined. Generally, questionnaires are used to subjectively measure the discomfort and the impact of tinnitus in the patient’s quality of life. An example is provided by the *Tinnitus Handicap Inventory* (THI), which was developed in 1996⁶ and exists in various versions in several languages, including Brazilian Portuguese⁷. Although one of the most common tools for tinnitus evaluation worldwide, questionnaire-based assessments are subjective and are not capable of measuring the magnitude of the patient’s discomfort and the degree of disability caused by the symptom in an objective manner.

Similarly, acuphenometry is one of the oldest methods for evaluating tinnitus and is still widely used. In fact, it can define the frequency (*pitch*) and intensity (*loudness*) of the tinnitus, as well as the minimum masking levels⁸ (MML) and the residual inhibition⁹, which are internationally known as the psychoacoustic measures.

One of the first acuphenometry records dates to 1931¹⁰, when a research on the *loudness* and *pitch* of tinnitus was performed with an acoustic stimulation of the pure tone type. Furthermore, the *loudness* balancing technique became widespread in 1938 to test the effect of tinnitus on hearing acuity when the contralateral ear is tested¹¹.

In 1985, during a Symposium of CIBA-GEIGY (now Novartis), which is headquartered in London, efforts were concentrated on standardizing a protocol for the evaluation of tinnitus, including the measurement of

pitch, *loudness*, minimum masking level, and residual inhibition⁹.

Previous literature reports that the psychoacoustic measures can be obtained through three different methods, i.e. the adjustment, limits, and adaptive methods¹². The adjustment method relies on the patient to adjust the stimulus (pulsatile tone) until the sound that is considered similar to his/her tinnitus is identified. In contrast, in the limits method, the patient is instructed to choose whether the stimulus presented (pulsating tones, ascending and descending, in increments of 1/6 octave) is more bass or treble when compared to his/her tinnitus. Finally, the adaptive method, also referred to as the “*Bracketing*”, requires the patient to determine whether the acoustic stimulus presented is bass or treble, but with increments of one octave. To guarantee reliable results, the tests are suggested to be repeated seven to nine times, regardless of the method used.

A debate regarding the type of stimulus to be utilized and the question of laterality (i.e. the presentation of the stimulus in an ipsilateral or contralateral way in relation to the ear where the tinnitus occurs) remains. In fact, while some authors use the contralateral measure as it is less confusing for the patient¹³, others prefer the ipsilateral measure to avoid the effects of diplacusis binauralis¹².

Knowing how researchers and clinicians have conducted the audiological psychoacoustic measurements for the assessment of tinnitus will be of great importance to objectively validate this auditory symptom, which is subjective, by definition. Such measures might be important for counseling, follow-ups, treatment-of-choice to be prescribed according to the suspected individualized diagnosis, and specifically for scientific research.

Although the literature categorizes the methods for conducting tests for psychoacoustic measurements, standards to obtain such parameters do not yet exist, in the field of audiology or in scientific research. Given the importance of the standardization of acuphenometry for the diagnosis and characterization of tinnitus, the purpose of this study was to review the national and international literature for methods of implementation of the psychoacoustic measures.

METHODS

The current integrative literature review was conducted on the articles present in specialized journals, both national and international in English

and Portuguese, which are available in the following databases: *US National Library of Medicine (PubMed/Medline)*, *Virtual Health Library - Latin American and Caribbean Literature on Health Sciences (BVS - LILACS)* and *Scientific Electronic Library Online (SCIELO)*.

To identify the articles relevant to our study, we considered terms related to the theme of

“psychoacoustic measures in tinnitus”, found in the Health Sciences Descriptors (DeCS), and the *Medical Subject Headings (MeSH)*, as well as keywords relative to the topic, and combined them with the use of the Boolean operators *AND* and *OR*. The terms chosen for the search were used in an isolated and crossed manner (Figure 1). Finally, the filter “word” was used in all the searches.

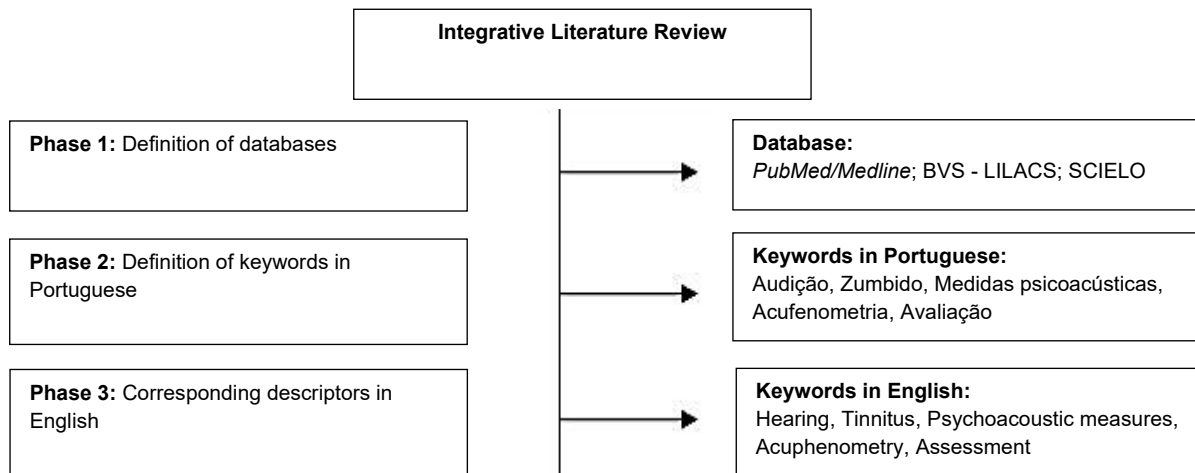


Figure 1. Determination of the databases as well as the keywords chosen for the integrative literature review

The main question underlying the present review was: “How are the psychoacoustic measures for the assessment of tinnitus recorded?”. To obtain the answers to this question, a survey of the articles was conducted in the mentioned databases, specific for each database without limiting the search period (Figure 2).

Initially, both the inclusion and the exclusion of the articles were based on the information included in their titles and abstracts. However, when the resulting information was not conclusive, the articles were read fully to check if the following eligibility criteria were fulfilled: the utilization of psychoacoustic measures for the measurement of tinnitus, and the presence of a clear explanation of the method used, both in individuals within normal hearing thresholds and in those with hearing loss. Articles were excluded for the following reasons: they quoted the psychoacoustic measures used for the evaluation of tinnitus but did not present their description, they reviewed the literature and/or methodology, they used a software for measuring the characteristics of tinnitus, they employed animals,

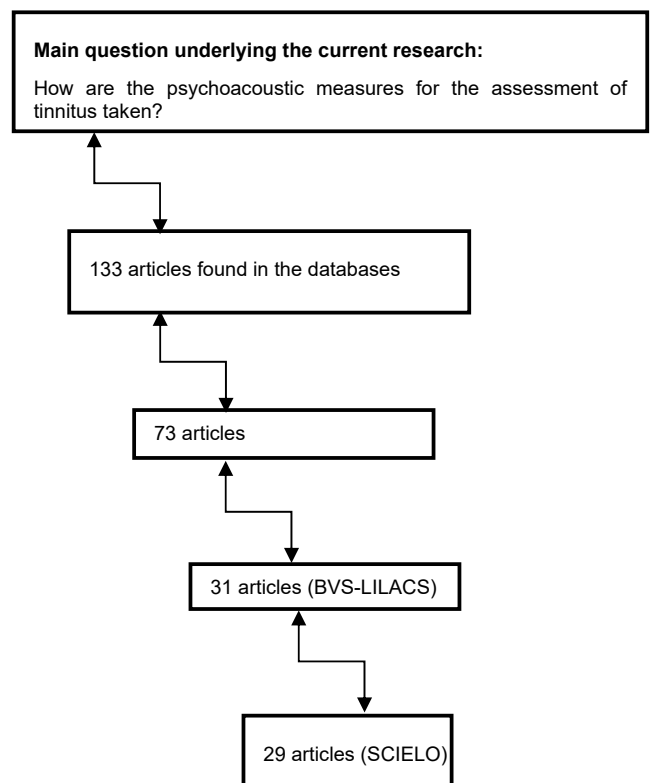


Figure 2. Selection process of the articles considered for the literature review

and when only the summary and/or “abstract” were available.

The selected articles were analyzed, initially by reading the titles and abstracts, followed by a full reading of the articles that met the eligibility criteria. Each article was evaluated by one of the authors and, in case of doubt, a consensus was reached among all the authors regarding the inclusion of the article in the review. The publications which were found eligible for this review were organized into figures to extract the following information: year, author(s) of the research, purpose(s), sample characterization, and evaluation mode of the acuphenometry.

Finally, the articles that resulted from each crossed term (which was repeated in relation to the previous search and was related to the present study) were computed to organize the data.

LITERATURE REVIEW

As a result of the search performed in the *Pubmed/ Medline*, LILACS and SCIELO databases, 133 articles were found (73, 31 and 29, respectively). All the mentioned articles were identified in one or more databases. While reading the abstracts, duplicate articles (i.e. had previously been selected in other databases), those that did not meet the inclusion

criteria and those for which the full text was not available during the period of the search were excluded.

Successively, the 133 abstracts, which were selected were read and the following were excluded: 30 due to the unavailability of the full text, 33, which only mentioned the psychoacoustic measures that had been used for the evaluation of tinnitus, three that did not address the context of the “psychoacoustic measures and tinnitus”, eight that only measured tinnitus by the use of questionnaires, six, as they were literature review studies, eight that reported studies measuring tinnitus with a software, one that only described the validation of an instrument for the evaluation of tinnitus, and two that were not available in both English and Portuguese. Finally, 29 articles were available in more than one database and were also excluded from the review.

After this detailed analysis, 12 articles that met the criteria for the current review were selected. Specifically, while seven were obtained from international journals, five were published in national journals. A summary of the articles published in the national journals relative to the use of psychoacoustic measures and their method of applicability for the assessment of tinnitus is shown in Figure 3.

In contrast, a summary of the articles published in the international journals is illustrated in Figure 4.

Year/ Authors	Objective(s)	Characterization of the sample	Assessment mode used in the acuphenometry
Rocha, Mondelli, 2017 ¹⁴ .	To determine the effectiveness of the SG associated with the counseling in the treatment of T in individuals with and without HL in relation to the improvement of discomfort and the HI.	30 individuals of both genders, distributed in: G1 – 15 individuals with normal hearing and an average of 55.87 years of age, and G2 - 15 individuals with HL of the sensorineural type, bilateral and symmetric, mild to moderate.	Research on pitch: Investigated with either pure tone or NB noise according to the characterization of the frequency of the T affecting the individual. The stimuli were presented 5dB more intense than the hearing thresholds at each frequency researched. Research on loudness: Research made at the frequency previously estimated, increasing the intensity of the acoustic stimulus in steps of 5dB, according to the characterization of the intensity of the T affecting the individual. Such psychoacoustic measures were again tested and the average of the values obtained was calculated. When the suppression of T occurred (partial or total), repetitions were not measured due to the absence of the symptom.
Benin et al., 2016 ¹⁵ .	To analyze and compare T and its impact on individuals with and without HL, as well as its characteristics relative to pitch, loudness and location.	50 individuals of both genders, 29 to 69 years old, divided into normal hearing and HL groups.	Research on pitch: Additional 10 dBNA were added relative to the auditory threshold of each frequency, with the acoustic stimulation of the pure tone type or noise, as per the description of the T characteristics. Research on loudness: On the frequency chosen by the patient as similar to his/her T, the stimulus was presented with an initial intensity of 10 dBNA below the threshold of the patient. Successively, the intensity was increased in steps of 2 dBNA and the patient was requested to signal when the intensity presented was similar to his/her T. This intensity was recorded and subtracted from the hearing threshold of the individual and this calculation determined the intensity sensation of T in dBSL.
Suzuki, Suzuki, Yonamine, Onishi, Penido, 2015 ¹⁶	To demonstrate the effectiveness of ST by monitoring the patients with different types of SG, the relation of sequential assessments using previously established parameters (THI, VAS, MML) and the need for individual interventions detailing the custom settings of these SG in patients without a response to previous treatments for T.	10 individuals, 41 to 78 years old, complaining about continuous chronic T for more than one year, without improvement when treated with medicative therapies and without specific treatment for T at least for three months.	The type of T they presented was taken into consideration and characterized in acuphenometry: T of the "whistle" type equal to the pure tone, the "wheezing" type similar to either the WN or NB, and the group with both types of T. The same criteria for the assessments and adjustments were followed in all groups. With regards to the MML, the research focused on determining which was the lower masking intensity of the T in an ascending way, using noise bilaterally (first WN followed by NB at the frequency of the T and then NB at 500 Hz).
Urnau, Tochetto, 2011 ¹⁷ .	To analyze the characteristics of T and hyperacusis in individuals with normal hearing, as well as the associated complaint of T and hyperacusis	25 individuals with normal hearing of both genders, 21 to 70 years old.	Only the T pitch research was conducted. Either a pure tone stimulus, a NB or a WN was presented in the contralateral ear in relation to the T. In cases of bilateral T, the stimulus was presented in the contralateral ear to the more intense T. The stimulus was provided at an intensity of 15 dBSL in the frequencies of 250 to 8000 Hz until the individual could identify the frequency of his/her tinnitus. To determine the compatibility between the pitch reported by the patient and the one determined by acuphenometry, the NB and pure tone stimuli above 1 KHz were classified as treble, while those below 1 KHz were defined as bass. Given that the WN covers an extensive range of frequencies, it was considered compatible with any <i>pitch</i> mentioned, either treble or bass.
Moura, Lório, Azevedo, 2004 ¹⁸	To check the efficiency of the adaptation to PSAPs in the reduction or elimination of T in patients with HL. To characterize the T. To determine other factors that might interfere with the improvement of T, such as length of usage and characteristics of the PSAP.	47 individuals of both genders, 33 to 88 years old, with HL of the sensorineural type, mild to profound, unilateral or bilateral, with T and with a medical indication to adaptation to PSAPs.	Research on pitch: Either pure tone type stimuli or NB (depending on the type of T) were presented to the contralateral ear in relation to the T, at 15 dBSL, at various frequencies, until the individual could identify the frequency of his/her T. Research on loudness: From the established frequency, the intensity of the stimulus was decreased by 5dB each time, until the individual identified the intensity closest to his/her T.

Caption: THI = *Tinnitus Handicap Inventory*; SG = sound generator; *pitch* = sensation of sound frequency *loudness* = sensation of sound intensity; MML = minimum masking level; PSAP = personal sound amplification product; HL = hearing loss; dBSL = decibels sensation level; ST = sound therapy; VAS = visual analogue scale; T = tinnitus; HI = hearing impairment; NB = *Narrow Band*; WN = *White Noise*; Hz = *Hertz*.

Figure 3. Synthesis of the national articles selected and analyzed for the present review (n=5)

Authors/ Year	Objective(s)	Total of subjects	Assessment mode used in the acuphenometry
Ibraheem, Hassaan, 2017 ¹⁹	To examine the relationship between the psychoacoustic measures of T and the auditory temporal resolution in individuals with normal hearing.	30 individuals of both genders, 20 to 45 years old, distributed as: 15 individuals with normal hearing and without complaints of T and 15 with normal hearing with complaints of T.	Research on pitch: It was conducted in the ear without T when T was unilateral and in the better ear when it was bilateral. A stimulus was presented starting from 1,000 Hz at 5-10 dBSL, followed by increases and decreases of the octave, according to the description of the participants. Research on loudness: The frequency determined during the research of the tinnitus' <i>pitch</i> was used, at a level below the threshold and the intensity was increased in steps of 1 dB until a correspondence to intensity was identified. The correspondence of <i>loudness</i> was expressed in dBSL.
Seimetz, Teixeira, Rosito, Flores, Pappen, Dall'igna, 2016 ²⁰	To analyze the existence of an association between hearing thresholds, the tone and the intensity of T in patients with presbycusis, according to gender.	49 individuals with presbycusis diagnosis and presence of unilateral or bilateral tinnitus, both genders, average age of 69.57 years.	Research on pitch: The research on <i>pitch</i> was conducted using all the frequencies, adding 10 dBNA at the hearing threshold for each frequency and either a pure tone or noise, depending on the characteristics of T. Research on loudness: It was performed according to the frequency found in the research on <i>pitch</i> , with an intensity of 10 dBNA below the hearing threshold, increased in steps of 2 dB, until the intensity presented was similar to that of T. The sensation level was calculated by subtracting this intensity from the hearing threshold frequency.
Heyning et al. 2014. ²¹	To evaluate the effectiveness and safety of the intratympanic procedure AM-101 in patients with acute internal persistent T after acoustic trauma.	248 individuals aged between 16 and 65 years, with a diagnosis of either HL of the idiopathic sensorineural type or chronic otitis media.	The MML is a descending method, started at 70 dBNA with pulsatile noise. Specifically, the intermediate point between the audible and the inaudible is the MML. Correspondence to the loudness: A tone of 1 KHz pulsatile was presented at an intensity of 15 dB above the threshold. The participants were asked whether the tone presented was stronger or weaker than the intensity of T. The intensity was adjusted in steps of 1 dB until the exact value was determined. These procedures were performed three times and the result was the average of these values, as long as the value was within a range of 5 dB. In the case of extreme values, a new measurement was performed.
Santos, Bento, Medeiros, Oiticica, Silva, Penteado, 2014 ²²	To determine whether the combined use of PSAPs and SG is more effective than the use of PSAP alone in reducing the discomfort of T in patients with T and bilateral symmetrical sensorineural HL, mild to moderate, using a new PSAP with an integrated SG developed by the Department of Otolaryngology of the XXXX.	49 individuals of both genders, aged between 21 and 72.1 years. All of them showed HL of the bilateral symmetrical sensorineural type, mild to moderate, with complaints of constant T for, at least, six months and without previous experience with either PSAP or other types of ST.	Research on pitch: The participants were instructed to relate the most uncomfortable frequency with the perception of T. In the cases of asymmetrical T, the contralateral ear was used as the reference, whereas the RE was used as the reference in the case of symmetric T in either both ears or in the center of the head. A pure tone stimulus type was used, except for those cases where the patient described the T as treble. The stimulus was presented at a level 5-10 dB above the hearing threshold of each frequency, starting at 1,000 Hz and was either increased or decreased according to the instructions of the individual. Research on loudness: The ear and frequency used in the research of the <i>pitch</i> were. The stimulus used for the research of the <i>loudness</i> was initially presented below the hearing threshold and increased in steps of 2 dB until the participant acknowledged an equivalence of the intensity to the T. With regards to the MML test, the WN stimulus type was presented below the hearing threshold and was increased in steps of 5 dB until the participant indicated that the T was either masked, partially masked or unchanged.
Ooms, Meganck, Vanheule, Vinck, Watelet, Dhooge, 2011 ²³	To investigate whether the severity of T is a problem related to depression.	136 individuals with an average age of 49.11 years and complaints of T. All participants were medicated with antidepressant drugs and 12 were receiving psychological counseling for T.	Concordance of the pitch and loudness: This was an alternative procedure related to forced-choice pairs. Two tones were presented to the participants, who were instructed to choose which of them was more similar to their T, both in terms of frequency and intensity. Subsequently, for the concordance of the <i>pitch</i> , an octave confusion test was performed, in which participants should identify a tone as similar to their T. With regards to the concordance of the <i>loudness</i> , the sound stimulus was presented in the frequency of T chosen by the participant, at a level of intensity below the threshold, and the intensity was increased until the patient signaled an existence of concordance.
Seidman et al., 2008 ²⁴	To check the effect of electrical stimulation on the auditory cortex of patients with tinnitus.	Two individuals aged between 40 and 50 years with severe debilitating tinnitus.	Concordance of pitch: Pure tone stimuli were presented, starting at 1,000 Hz, until the approximate <i>pitch</i> was chosen. Once the estimate was determined, the alternative procedure of forced-choice pairs was performed to determine the <i>pitch</i> . Tones distant of one octave to the chosen one were presented as a choice to discard the confusion octave. Seven choices of <i>pitch</i> were made in an attempt to increase reliability. Ipsilateral measures were conducted to ensure the exclusion of diplacusis binauralis in the concordance. Concordance of loudness: They were performed using the frequency determined in the <i>pitch</i> concordance. A continuous tone was presented below the threshold, to the contralateral ear, and increased by 1 dB every two seconds until the patient indicated that the tone was equivalent in <i>loudness</i> to T. Three concordances were obtained, and the final tally was recorded in dBSL. To obtain the MML, the WN was ipsilaterally presented at the intensity of 10 dB below the AL and was increased until the patient could hear it. The level of masking was then lowered and increased until the patient indicated that the WN masked the T.

Authors/ Year	Objective(s)	Total of subjects	Assessment mode used in the acuphenometry
Kroner-Herwig et al., 1995 ²⁵	To differentiate the effectiveness of a non-specific program (yoga) versus a specific program of target problem (training on T) and examine the pattern of effectiveness using a wide range of outcome variables (psychoacoustic/daily/psychometric/global self-description).	43 individuals with an average age of 48 years and complaint of chronic T, assessed immediately after the therapy and during the 3-month follow-up.	The level of sensation of T was measured by asking the patient to match the level of intensity and the frequency of a sound similar to his/her Z. The sound level (dB) was related to the auditory thresholds. The level of T masking was determined for both ears. A frequency spectrum between 125 Hz and 10,000 Hz was presented to each ear. A single parameter of masking level of the T was used for each individual, calculating the median of all levels of masking recorded.

Caption: MML = *Minimum masking level*; PSAP = personal sound amplification product; rTMS = repetitive transcranial magnetic stimulation; dBNA = decibels auditory level. KHz = kilohertz; SG = sound generator; ST = sound therapy; RE = right ear; Z = tinnitus; MML = minimum masking level; AL = auditory level; CG = control group; EG = experimental group; dBSL = decibels sensation level; HL = hearing loss; dB = decibels; WN = *White Noise*; ORL = Otorhinolaryngology

Figure 4. Synthesis of the national articles selected and analyzed for the present review (n=7)

This study presents an overview of the research developed under a national and international scope, using psychoacoustic measures to assess and characterize tinnitus, in both individuals with normal hearing and hearing loss. In addition, we have also described the use of these psychoacoustic measures in guiding researchers and professionals in the evaluation of patients with tinnitus.

Based on the studies analyzed, we could infer an absence of consensus on the standardization of the measurement of tinnitus while performing acuphenometry, which may influence the results of the assessment. The divergent results may be caused by extrinsic (how the guidance prior to assessment is made) and intrinsic factors (variation of the loudness intensity in the research). However, most of the studies describe the correspondence between *pitch* and *loudness*, as well as the type and intensity of the stimulus presented, according to the severity of the patient's tinnitus.

With regards to the national literature, pure tone, *white noise* and *narrow band*^{16,17} stimuli were used to determine both the *pitch* and *loudness* of tinnitus. The intensity of both *pitch* and *loudness* were found to vary between 5¹⁴, 10¹⁵ and 15dBNS^{17,18}.

Furthermore, the researchers of two studies measured and characterized tinnitus either in the contralateral ear or in the ear in which the tinnitus was not prevalent^{17,18}.

In the international literature, pure tone^{20,22}, noise²⁰ and pulsatile²¹ stimuli were used to determine the *pitch* and *loudness* of tinnitus.

Moreover, we observed the applicability of the Minimum Masking Level (MML) in the characterization and the measurement of tinnitus on the different

protocols which were found to be used. The MML is a psychoacoustic estimate of the lowest level of broadband noise to minimally mask the tinnitus in the patient²⁶.

Two studies (one national¹⁶ and one international²¹) reported that the measuring the MML of tinnitus could be used as a complementary method to the identification of loudness in acuphenometry. However, the remaining studies only used the correspondence between the pitch and the loudness to perform the acuphenometry, showing great heterogeneity in their protocols.

CONCLUSION

Given the grouping of several protocols for tinnitus evaluation, which were determined following an integrative literature review, a great heterogeneity in the methods used to perform psychoacoustic measurements for tinnitus assessment for both clinical and scientific purposes was noted.

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