Research Article

The Effect of Root-Mean-Square and Loudness-Based Calibration Approach on the Acceptable Noise Level

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Short running title: The Effect of Root-Mean-Square and…

Highlights:

- The choice of RMS and loudness-based calibration had no impact on the ANL results
- No significant effects on monotic/dichotic ANL from calibration methods

ABSTRACT

Background and Aim: Hearing and speech perception are essential in social life. As our environment contains many background noises in everyday conversations, it is necessary to evaluate the noise tolerance. The Acceptable Noise Level (ANL) provides an approach to quantifying the maximum amount of background noise a listener is willing to put up with while listening to a target story without becoming tense. Exploring noise tolerance in speech perception, the study investigates how different calibration methods impact normal hearing participants' monotic and dichotic ANL results.

Methods: This investigation utilizes a pared-sample t-test for statistical analysis, adopting a comparative observational approach. This study applied the Persian version of the typical ANL test. Two approaches have equalized the target and background stimuli: Root Mean Squared (RMS) and loudness match calibration via Adobe Audition. Using these modified materials the Most Comfortable Level (MCL), the Background Noise Level (BNL), and ANL were compared in terms of RMS and loudness match calibration. Fifty normal persons aged (18–39), under the conditions of monotic and dichotic listening, participated in this study.

Results: The statistical analysis using a paired-sample t-test revealed no significant differences in the outcomes of the ANL test between the calibrations of RMS and loudness matching under both monotic and dichotic listening conditions ($p=0.31$ and $p=0.67$, respectively).

Conclusion: The study suggests that calibration procedures, namely RMS and Loudness matching, do not affect ANL in either monotic or dichotic conditions.

Keywords: Loudness; calibration; acceptable noise level; root mean square

Introduction

Hearing and speech perception hold significance in social interactions. Difficulty in speech perception can lead to limited social engagement and isolation [1]. The auditory environment we encounter daily is characterized by a wide range of sounds with varying loudness and spectral and temporal characteristics, many of which can be described as noise [2], and it is known that it disrupts the ability to perceive desired signals, such as speech [3]. Given the prevalence of background noise and babble noise in everyday conversations, it becomes essential to assess noise tolerance in such environments [4]. One notable measure for evaluating this tolerance is the Acceptable Noise Level (ANL), which quantifies the maximum level of background noise a listener can endure while following a target story without experiencing tension or fatigue [5]. According to previous research, the authors have demonstrated that the ability to tolerate background noise is associated with higher-level processing within the upper brainstem and cortical regions [6].

ANL measurements exhibit significant variability across listeners, potentially stemming from genuine individual differences in noise tolerance [7]. As per prior research, variables including the speaker's gender [8], listeners' age [5], gender [9], and auditory sensitivity [10], have exhibited no influence on the outcomes of ANL assessment. However, features like the type and valence of background noise and monotic or dichotic presentation have been found to affect ANLs [11, 12].

In determining why listeners are willing to tolerate the amount of background noise, factors like sound acoustic with the interest level of the speech material [8], loudness tolerance [13], and changes in speech presentation level [7] have been studied. Loudness was selected because it is a simple concept that most people can comprehend. Additionally, it is generally accepted that the intensity of a sound has a significant impact on loudness perception [13, 14]. Individuals may be unwilling to endure elevated Background Noise Levels (BNL) due to calibration problems. It's crucial to calibrate sound intensity measurements for clinical audio recording and analysis because recordings are made using various microphones, amplifiers, and computer setups. Standardizing methods is crucial to ensure consistent and reliable results when comparing sound recordings within and across headphones, speakers, and research. Failure to account for these factors can hinder accurate data collection and analysis [15]. While changing both the mean and maximum values have been proposed as estimates for loudness perception in models for time-varying sounds [15], this study wanted to investigate whether listeners' ANLs are consistent with different calibration strategies based on Root-Mean-Square (RMS) and loudness-based calibration, not the peak amplitude. In this case, the RMS represents the average power of the entire signal to measure the overall loudness of the waveform selection and more closely matches how people hear volume. In comparison, loudness-based calibration via Adobe Audition (Adobe Co., 2017, USA) emphasizes corresponding to a perceived amplitude and frequency that vary considerably based on the human ear's sensitivity. It must be remembered that speech interference may contribute to both top-down processes and bottom-up neural representations, which can alter our perception of the same physical stimulus [16]. Some individuals have stable ANLs regardless of speech level, indicating that they use speech intelligibility as their primary criterion for noise acceptability. In contrast, others show changes in ANL with speech level, suggesting a different perceptual criterion, such as listening comfort [7]. An ongoing debate centers around the role of speech intelligibility in ANL, with varying results reported [17].

In light of these findings, it is apparent that individuals employ different criteria for evaluating their noise tolerance. However, the specific extent and nature of these criteria remain unclear. Hence, it aims to investigate whether the methods used for loudness calibration affect noise tolerance in participants with normal hearing. To the authors' knowledge, this study is the first to measure ANL with different calibration procedures in normal-hearing individuals. The findings of this study are expected to contribute to the understanding of ANL in individuals with normal hearing and facilitate comparisons with those with hearing impairments. Furthermore, a comparison of the behavioral tasks involved in monotic and dichotic ANL can identify the perceptual demands associated with each type of ANL [12, 18]. The study involves testing ANLs with monotic and dichotic presentations of background noise, providing insights into the impact of these factors on noise tolerance.

Methods

Participant

Fifty individuals (34 females and 16 males) aged 18–39 (mean: 22.58, SD: 4.08) participated in this study. These individuals were recruited from students at (the Rehabilitation School of Shahid Beheshti University of Medical Sciences (SBMU), Tehran, Iran). It was desired that all audiometric thresholds equal 20 dB HL or less and that the thresholds for the two ears be symmetric (within 10 dB at each frequency).

Testing was completed in one testing session lasting approximately 30 minutes, with the possibility of pausing when needed. All testing was performed in a sound-treated booth. Before testing, each participant was given verbal instructions describing the experiment and experimental tasks.

Calibration

In this study, the target and background stimuli were controlled to have equalized loudness matching values by RMS amplitude, calibration, and loudness match via Adobe Audition software (Adobe Co., 2017, USA). Multi-talker babble noise needed to be normalized to have the same energy to ensure equal contribution as well [19]. It should be noted that although all babble noises consisting of between 8 and 128 talkers had approximately the same masking effectiveness, the eight-talker babble provided the greatest amount of masking [19]. It was speculated that the 8-talker and 12-talker babble maskers may be similarly unintelligible, with no significant difference [20]. According to previous studies, which mentioned using 12-talker babble [5, 21], we used the same. RMS tells the average power of the signal over time. Because speech is a dynamic signal, the standard approach to some calibration checks is to use one of several consistently repeatable nonspeech input signals (e.g. a pure tone of 1000 Hz) [22]. The speech and babble signals were calibrated by arbitrarily matching equal to the loudness of a 1000-Hz tone (the calibration tone) played through the system and adjusted to produce a reference level of 0 dB on the monitoring meter before starting a test. Then, the recorded speech signals presented with acceptable minor deviations around 0 dB on the monitoring meter during testing. The SPL is the Reference Equivalent Threshold Sound Pressure Levels (RETSPLs) for air-conducted speech stimuli delivered via earphones, which is used to achieve a 0 dB HL threshold level for speech. According to ANSI/ASA S3.6–2010, the RETSPL for speech presented for TDH 39 earphones should be 12 dB above the 1000 Hz standard RETSPL (7.5 dB), which means 19.5 dB (7.5 dB+12 dB) [22].

In loudness calibration via Adobe Audition (Adobe Co., 2017, USA), the loudness of two stimuli of target and babble background noise were matched by a perceived amplitude. Adobe Audition uses an equal loudness contour, where the mid frequencies are most important. Since the ear is less sensitive to very high and very low frequencies and much more susceptible to those frequencies between 2 kHz and 4 kHz, two different pieces of audio with the same RMS amplitude but that contain different frequencies will sound like they have differing volumes.

Figures 1 and 2 represent the descriptive value for different calibration approaches. Figure 3 illustrates the intensity difference between RMS calibration and loudness match via Adobe Audition over frequencies.

Procedure

The baseline hearing thresholds for air and bone conductions were determined using the Hughson-Westlake procedure in a soundproof booth, employing a clinical audiometer (AC40, Interacoustics Co, Denmark). ANL measurements for each participant were obtained following the approach outlined by Nabelek et al. [5]. In this study, all participants were proficient in the Persian language. Consequently, a Persian version of the ANL test was employed, featuring a Farsi story narrated by a female speaker as an auditory target and a 12-talker babble noise as a competitive signal [21]. According to the International Organization for Standardization (ISO), when constructing and calibrating speech intelligibility tests, it is recommended that authors use masking noises with spectrums that are similar to those of speech. This ensures that the noise will have an equal effect on speech for every frequency band and will closely resemble everyday environmental noises, such as the babble resulting from several voices heard simultaneously [23].

The sounds were delivered to the participant using headphones (TDH-39) connected to a clinical audiometer (AC40, Interacoustics Co, Denmark). The audiometer was connected to a Dell Co. laptop through a 2.5 mm audio jack. Each participant was instructed to communicate with the examiner through hand gestures (thumb up for volume increase and thumb down for volume decrease) to adjust the loudness of the speech or babble noise.

The ANL is a speech-in-noise measure involving listeners self-selecting an acceptable BNL [5]. ANL represents the maximum BNL an individual can tolerate while listening to continuous speech. The ANL value can be obtained by taking the difference between the Most Comfortable Level (MCL) of a speech stimulus and the highest BNL that can be tolerated.

Following the method outlined by Nabelek et al. [5] the participant's MCL was initially determined. The MCL for speech was determined using a bracketing procedure involving 5 dB increments starting at 30 dB HL. The participant adjusted the speech level in ascending and descending trials, and the level where they found it most comfortable was recorded as the MCL. For the MCL, participants were instructed to adjust the speech level to their comfort level and signal “OK” when they reached that level. The verbal instructions for MCL were as

follows: you will be listening to speech. Your job is to adjust the level of the speech to a level that you would consider most comfortable, and finally say "OK" when you have reached that level.
Subsequently, the BNL was selected using a bracketing procedure similar to that used for MCL determination. For the BNL, participants were instructed to adjust the background babble noise to the maximum level they would accept without experiencing tension or fatigue while listening to the speech. The noise level began at 30 dB, increased in 5 dB increments until the participant indicated that it was unacceptable (thumb down), then decreased in 2 dB increments until it became acceptable (thumb up). The verbal instructions for the BNL were as follows: "You will be listening to speech, and as you listen, you will hear background noise, which sounds like several people talking. Your task is to regulate the amount of ambient sound to a level that you find comfortable and can tolerate while listening to and comprehending the speech without feeling stressed or tired. Say "OK" when you have reached that level. This process was repeated until the same level was chosen twice as acceptable, which was then defined as the maximum BNL used for the ANL test.
For each presentation-level trial, two MCLs and BNLs were measured, allowing for the calculation of two ANL values. The two calculated ANLs were averaged to derive a single ANL value.
The effects of noise on each participant were assessed using two different behavioral measures: 1) ANL for monotic conditions (ANLm) was determined by subtracting the background noise accepted ipsilaterally from the MCL for running speech, in which both stimuli had been delivered into the right ear; 2) a dichotic ANL (ANLd) procedure was conducted, involving the simultaneous presentation of running speech to the participant's right ear and competing speech babble noise to the left ear, following a modification of the earlier-described procedure.

Statistical analysis
The statistical data, such as range, mean, and standard deviation using SPSS (v.17), are pointed out in Table 1. The data's normality was determined using the Shapiro-Wilk test, and a repeated measure analysis of variance (ANOVA) was performed on the ANLs' results. Polynomial comparisons were utilized to determine pairwise comparisons under each condition, and statistical data was obtained regarding Bonferroni correction. In addition, a paired 2-sample t-test and Wilcoxon were applied to calculate each condition sample pairing to show if there were any significant differences between the calibration of RMS and loudness in either monotic or dichotic conditions. In this study, the considered crucial significance was $p<0.05$.

Results
According to the data presented in Table 1, the ANL results for monotic conditions ranged from –5 to 12, with a median value of 0.00. For dichotic conditions, the ANL results ranged from –40 to 20, with a mean value of –12.00, 95% CI [116.61, –7.38] when employing the RMS calibration approach. Similarly, when utilizing the loudness-based calibration approach, the ANL results for monotic conditions ranged from –7 to 15, with a median value of –0.50, while for dichotic conditions, the range was –50 to 25, with a mean value of –11.30, 95% CI [–16.29, –6.30]. Additionally, the mean ANL outcome for monotic condition was 0.60, 95% CI [–0.37, 1.57] when using the RMS calibration approach, and 0.46, 95% CI [–0.88, 1.80] when employing the loudness calibration approach.
The data's normality was determined using the Shapiro-Wilk test. The test was insignificant for the ANLm (monotic condition) with two different calibrations (RMS and loudness procedures), indicating that the data did not follow a normal distribution. In contrast, the data was found to be normally distributed for the ANLd (dichotic condition) with two different calibrations, as indicated by the Shapiro-Wilk test.
Due to the non-normal distribution of data of the ANLm, the Wilcoxon test, a non-parametric test for comparing related samples, was employed to compare ANL values for speech-babble noise in monotic conditions with different calibrations (RMS and loudness procedures). The Wilcoxon test results revealed no statistically significant difference in ANL between the two calibration methods for the monotic condition ($z=-1.01$, $p=0.311$). In contrast, for the ANLd with two different calibrations, since the data was normally distributed, a paired 2-sample t-test was conducted to compare ANL values in dichotic conditions. The paired t-test indicated no statistically significant difference in ANLd between the two calibration methods for the dichotic condition ($t_{49}=-0.41$, $p=0.67$).
Four Violon graphs comparing two calibration approaches in each monotic and dichotic presentation condition separately (Figure 4).
A repeated measures ANOVA was performed on ANL values to confirm further the results contributing four factors as 2*conditions and 2*calibrations in this study. Greenhouse-Geisser corrections for violations in sphericity were applied. Mauchley's test of sphericity was significant [Mauchley's $W=0.079$, $p<0.001$], indicating a difference between ANLm and ANLd. The ANOVA results revealed a significant effect [$F_{(1.66,}$

$_{81.67)}$=27.35, $p<0.001$, Eta^2=0.358] related to the monotic and dichotic conditions. Based on the results of the paired 2-sample t-test and the Wilcoxon test, which revealed no significant differences in ANL between calibrations for dichotic and monotic conditions, the findings were confirmed by contrast polynomial comparisons. These comparisons showed no significant differences for the ANLd with two different calibrations ($p=0.67$) and the ANLm with two different calibration approaches ($p=0.74$). In other words, the calibration method did not significantly affect the traditional acceptable noise level (speech-babble noise) in either monotic or dichotic conditions.
Based on the statistical analysis, it can be inferred that the ANL values for both monotic and dichotic conditions were not significantly affected by the choice of calibration method, whether RMS or loudness-based procedure. These findings suggest that the traditional acceptable noise level remains consistent regardless of the calibration approach used, at least for the conditions applied for this study.

Discussion

Background noise has a well-established disruptive effect on one's ability to engage in listening tasks in everyday scenarios, necessitating high effort in maintaining listening comfort and sound quality, particularly in noisy settings [3, 24]. ANL is a critical measure for understanding an individual's tolerance for background noise while listening to continuous speech. An intriguing question is the relationship between ANL outcomes and loudness calibration as one of the acoustic features of sound.
The study's hypothesis aimed to investigate how different loudness calibration procedures affect the measurement of ANL in normal-hearing individuals. The results indicate that the calibration method, whether RMS or loudness-based via Adobe Audition, did not significantly impact ANL measurements in monotic or dichotic conditions. This suggests that the choice of calibration method, at least for these methods of calibration applied for this study, was a minor factor when assessing ANL in normal-hearing individuals.
The results regarding the first objective indicated that the amount of background noise willing to accept, whether presented monotically (ANLm) or dichotically (ANLd), remained similar with these calibration approaches. Participants accepted similar noise levels for both conditions, suggesting similar underlying processing mechanisms. This implies that individuals employed the same strategy for selecting an acceptable BNL. Comparing ANLm and ANLd conditions indicated potential differences in the internal processes required to perform these tasks, with subjects accepting higher levels of background noise in the contralateral ear demonstrating better performance in noise than in the ipsilateral ear. These results align with the notion that sounds are easier to identify when separated in space [25], as ANLs were smaller in the dichotic ANL task compared to the monotic ANL task, and the range of ANLd was broader than that for the ANLm measure [12, 18].
Individual differences in ANL measurements have been documented in previous research. This study supports the idea that ANL is a highly variable measure, potentially due to genuine individual differences in noise tolerance. This variability may be due to central auditory processing, rather than the peripheral auditory system when reconstructing messages presented in noise [6, 16].
Despite the considerable intersubjective variability, the consistency between the two loudness calibration methods is robust. As illustrated, the intensity difference between the two calibration approaches was relatively small for female speech sounds and babble noise. It must be borne in mind that we did not normalize the perceived loudness with the peak amplitude because the maximum amplitude of a sound cannot be relied upon as an indicator of its loudness.
The ANL's relationship with speech loudness level, which has been observed by multiple researchers [7, 26, 27], indicates that ANL judgments are increasingly influenced by loudness. Nonetheless, in this study, speech was adjusted to match participants' comfortable loudness levels. Regardless of its spectrum and temporal pattern, any sound that surpasses a certain level can be perceived as loud and/or irritating [28]. Additionally, acceptable noise levels are not necessarily linked to one's loudness tolerance [13] and may even decrease as speech levels rise above the most comfortable loudness level [7, 26].
The influence of noise on speech loudness is determined by the signal-to-noise ratio rather than the absolute level of the speech or white noise [29]. When two sounds are presented concurrently, as in the ANL test, the presence of one sound affects the perceived loudness of the other sound, a concept known as partial loudness [30]. Discussing partial loudness in the presence of multiple sounds emphasizes the complexity of ANL measurements. It underscores the importance of understanding how the presence of speech signals can influence judgments of the loudness of background noise, a phenomenon that could affect ANL outcomes. When the number of competing talkers increased from 1 to 8, the ANL significantly decreased. This was found even when the average RMS of the speech maskers was controlled to be equal. Surprisingly, the lowest ANL was obtained from the 8-

talker masker, while the higher ANL was obtained from the 1-talker speech masker. The reason for this could be that the 8-talker speech masker has acoustic characteristics similar to speech sounds, that did not provide meaningful interference as a masker and may be unintelligible as 12-talker babble maskers [20].
Speech intelligibility and its quality are distinct aspects of speech perception. Intelligibility measures how much of the speech has been correctly recognized and assesses the practical aspect of whether listeners can understand the original message in the target speech, while quality pertains to the clarity, naturalness, and absence of distortion in speech [31]. There are instances where speech of low quality can achieve high intelligibility, and enhancing intelligibility does not necessarily strengthen the quality, and vice versa [32]. Human speech communication often occurs in complex acoustic environments with multiple sound sources and ambient noise, and remarkably, the human auditory system maintains robust speech understanding in such situations by combining bottom-up processing of available cues and top-down application of learned patterns [33]. Since speech enhancement, focusing on improving intelligibility and quality, is crucial in restoring corrupted target speech by interfering with sources and acoustic channel transmission [7, 17], it seems that both of these calibration approaches are concerned with quantifying speech intelligibility or quality with acoustic features of speech and self-chosen maximum BNL [17].
Our interpretation of this study was that although the RMS approach seems a reflection of how people perceive volume, when compared with loudness match calibration, it produces almost identical loudness. Thus during two calibration approaches, listeners were willing to tolerate almost equal available redundancy for the meaningful target in that background sound and they accepted similar amounts of noise for the two conditions.
This study provided valuable information about a listener’s performance in noise abilities, and the findings of this study appeared to support this conclusion. Thus, it is suggested to provide unique insights into listeners' performance in noise beyond conventional speech and compare these results with other different loudness meters. This study encourages future research to delve deeper into the complexities of ANL and its relationships with speech perception and cognitive processes.

Conclusion
The study's focus on calibration methods adds to the existing literature on Acceptable Noise Level (ANL) by addressing an important technical aspect of its measurement. While calibration is essential for ensuring the reliability and accuracy of ANL assessments, the study suggests that variations in these two calibration methods may not substantially impact ANL outcomes in normal-hearing individuals.

Ethical Considerations

Compliance with ethical guidelines
This study has obtained approval from the Research Ethics Committee of Shahid Beheshti University of Medical Sciences under the reference number (IR.SBMU.RETECH.REC.1401.612).

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Authors' contributions
RN: Study design, data acquisition, statistical analysis, interpretation of the results, and manuscript drafting; FSG: Statistical analysis, manuscript drafting; HJ: Study design and supervision, critical manuscript revision.

Conflict of interest
There have been no conflicts of interest related to financial matters in this research.

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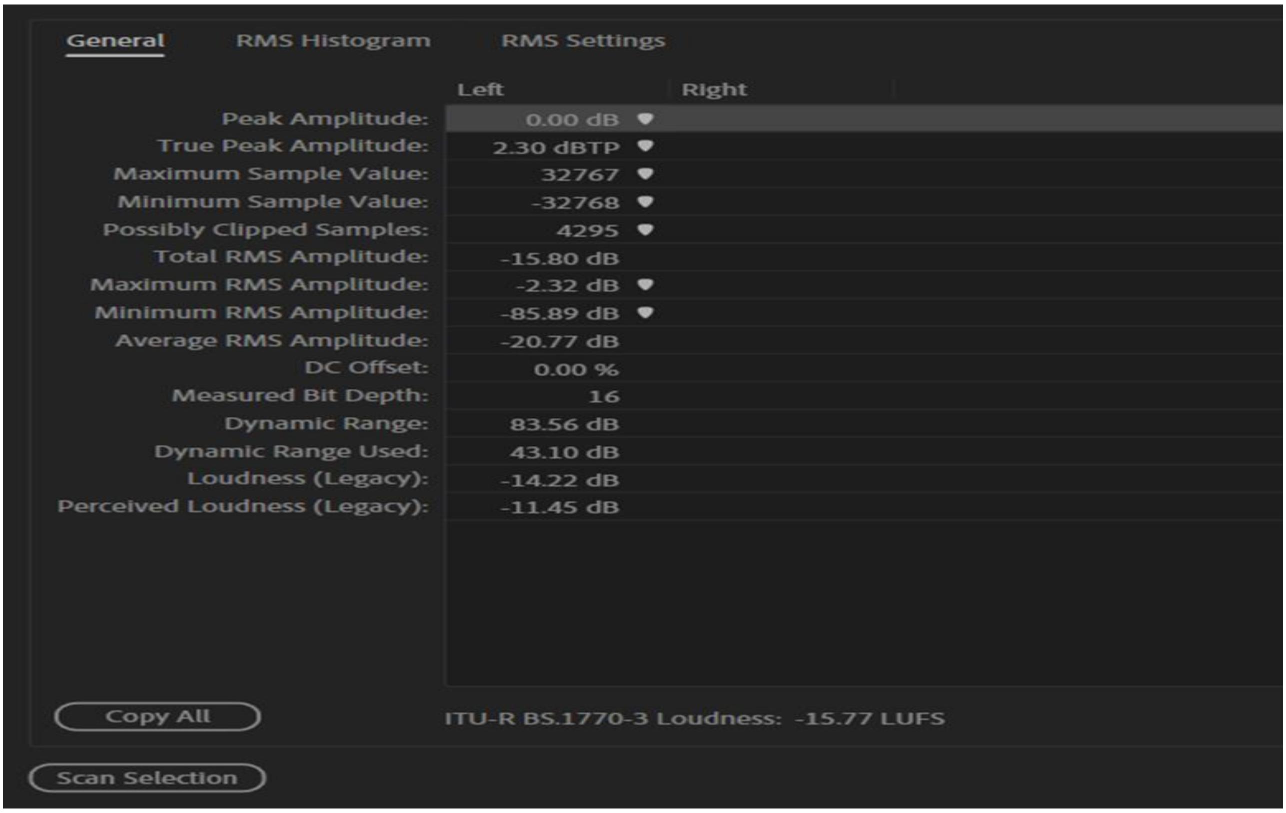

Figure 1. Loudness matches via Adobe Audition. Descriptive values of the peak amplitude, true peak amplitude, maximum sample value, minimum sample value, possibly clipped samples, total root mean squared amplitude, maximum root mean squared amplitude, minimum root mean squared amplitude, average root mean squared amplitude, dynamic range, dynamic range used, loudness (legacy), and perceived loudness (legacy) for different calibration approaches. RMS; root mean squared

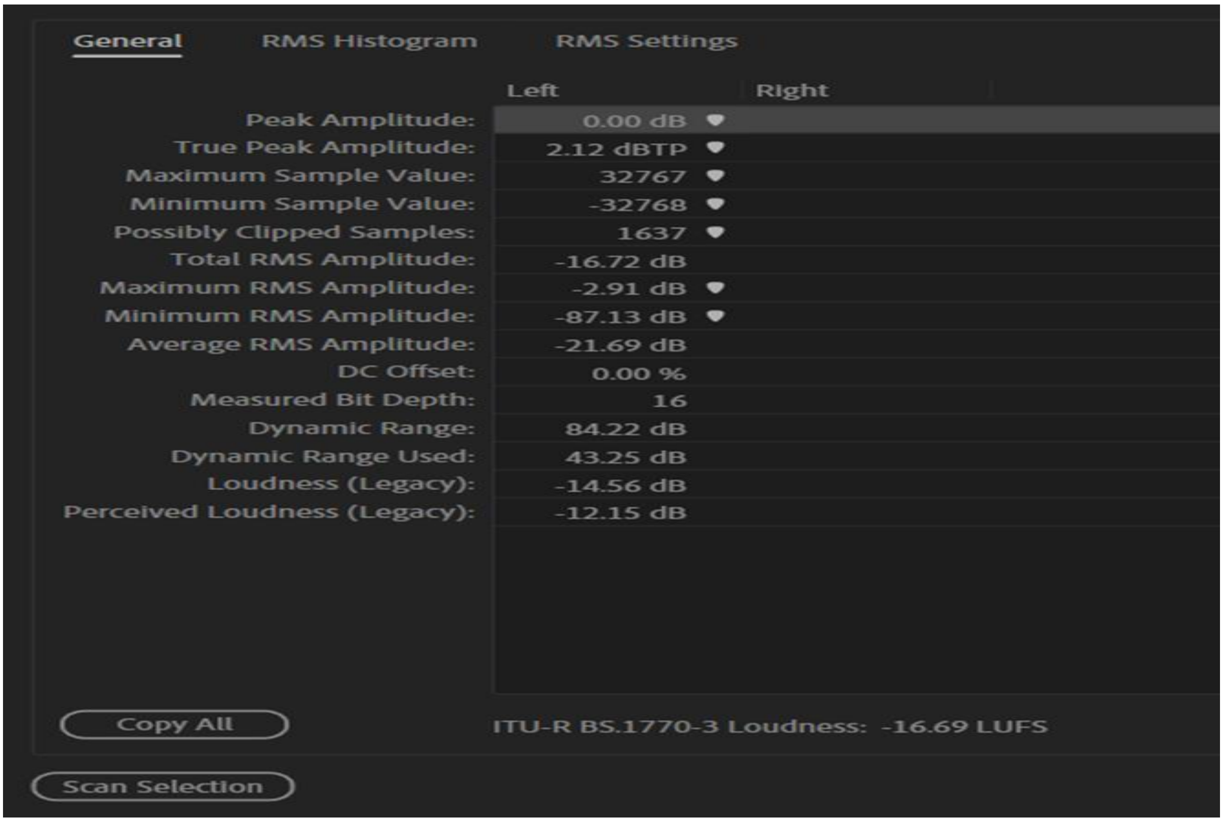

Figure 2. Root mean squared calibration. Descriptive values of the peak amplitude, true peak amplitude, maximum sample value, minimum sample value, possibly clipped samples, total root mean squared amplitude, maximum root mean squared amplitude, minimum root mean squared amplitude, average root mean squared amplitude, dynamic range, dynamic range used, loudness (legacy), and perceived loudness (legacy) for different calibration approaches. RMS; root mean squared

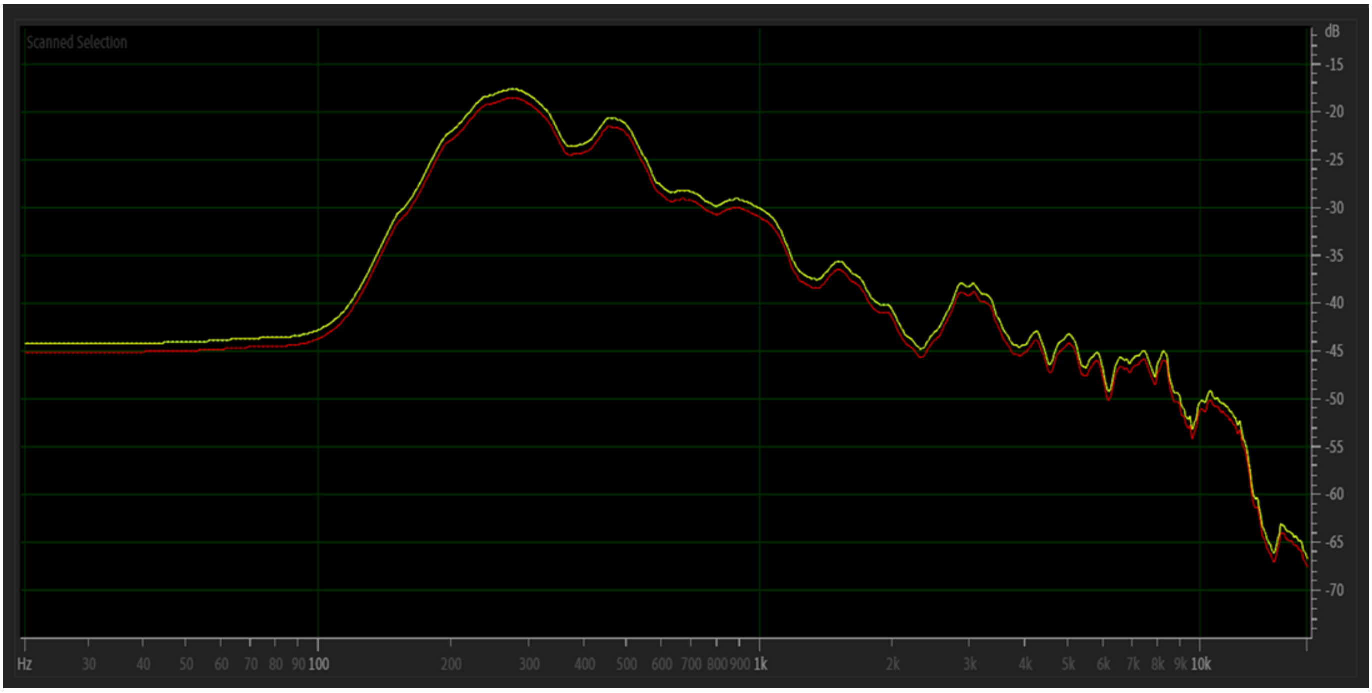

Figure 3. The long-term spectrum represents an analysis of sound levels recorded over time to determine sound levels in different parts of the frequency range. This graph illustrates the intensity difference between root mean squared calibration and loudness match via Adobe Audition over frequencies. Red curve: root mean squared calibration of female speech. Yellow curve: loudness match of female speech

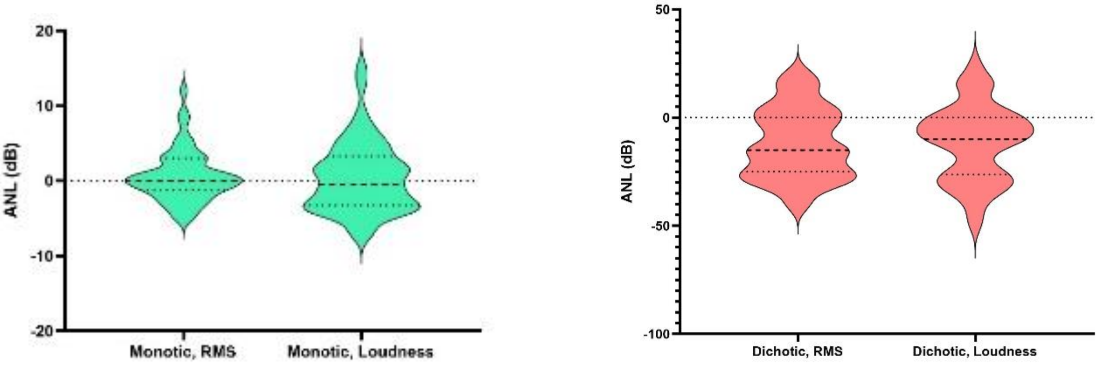

Figure 4. The violin plot, including the median and interquartile range of acceptable noise level values under root mean squared calibration and loudness match via Adobe Audition. Right chart: in monotic condition. Left chart: in dichotic condition. ANL; acceptable noise level, RMS; root mean squared

Table 1. The range, mean, and standard deviation of the most comfortable level, background noise level, and acceptable noise level for monotic and dichotic listening under two different calibration approaches

		Mean±SD(range)	
		RMS approach	**Loudness approach**
Monotic condition	**MCL**	64.30±7.95(50–80)	62.90±7.89(45–80)
	BNL	63.70±9.14(46–80)	62.44±9.70(42–81)
	ANL	0.63±3.42(–5–12)	0.46±4.73(–7–15)
Dichotic condition	**MCL**	63.10±8.32(45–80)	60.70±7.95(45–75)
	BNL	75.10±17.77(35–100)	72.00±17.69(30–100)
	ANL	–12±16.22(–40–20)	–11.30±17.57(-50–25)