ORIGINAL ARTICLE

Calibrating different sounds for sound therapy: A general guide

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ABSTRACT

Introduction: Sound therapy is one of the complementary or alternative interventions for various populations. The intensity of the sounds for sound therapy needs to be properly calibrated to ensure their accuracy and effectiveness. This paper aims to provide a general guideline for calibrating sound files using free software, specifically Audacity®.

Materials and Methods: Six sounds (broadband noise, rain, ocean, waterfall, Quranic chapters Al-Fatihah, and Yasin recitations) were calibrated at the intensity levels of 45, 50, 55, 60, 65, 70, 75, and 80dBA. The sounds were delivered through a pair of Sennheiser HD 280 Pro headphones connected to the Sound Blaster X-Fi Surround 5.1 Pro sound card. The long-term average of the sound pressure level over the time of recording (LAseq) was recorded using the 3M SoundPro Class 1 1/3 Octave RTA sound level meter (SLM). The desired intensity levels were obtained by making adjustments to the sound files via the Audacity® software.

Results: All sound files were calibrated at the targeted levels as verified by the value of LAseq.

Conclusions: Calibration of audio files can be done using a free/open-source software, as all six sound files were successfully calibrated at the targeted levels of 45, 50, 55, 60, 65, 70, 75, and 80dBA. The calibration steps provided in this paper can be easily applied by other researchers for similar purposes, with precautions when calibrating at low levels.

KEYWORDS:
Calibration, sound therapy, guidelines, nature sounds, Quranic recitations

INTRODUCTION

Medical interventions may be classified into two general categories: 1) preventive interventions, which aim to prevent the occurrence of a disease, and 2) therapeutic interventions, which aim to treat or alleviate symptoms of diseases that are already progressing in patients.[1] Sound therapy falls under the second category of interventions, as it aims to alleviate the symptoms of certain diseases or disorders.

In audiology, the use of broadband noise (BBN) and nature sounds as sound therapy (ranging from 0 to 100dB SPL) has been shown to provide some degree of relief to tinnitus sufferers.[2,3] Meanwhile, listening to Quranic recitations has been shown to reduce anxiety and pain in patients.[4,5] BBN as contralateral acoustic stimulus (at the level of 60dBA) is also known to be one of the most effective ways to activate the medial olivocochlear system (MOCS).[6-10] The activation of MOCS serves several important functions, such as aiding in selective attention,[11,12] providing protection from noise,[9,13-15] as well as aiding understanding of speech in noise.[6,16] Due to this, some research focused on the potential of using BBN as sound therapy for populations that may require it as a form of intervention. In addition, studies have shown that BBN at 75dBA could help boost the attention of children with attention deficit hyperactivity disorder (ADHD).[17,18]

These earlier studies show that sound therapy interventions aimed at different populations require different types of sounds and different intensity levels in order for it to be effective. Despite this, previous publications that utilized acoustic stimuli at a specific intensity level or at various intensity levels in their experiments do not always report in detail how the calibration process was carried out.[8,19] This may make it difficult for other researchers to refer to or understand the calibration process if they wanted to replicate it in their own studies.

Therefore, the aim of the current paper is to share a general outline of how sound files were calibrated in our study so that it could serve as a guide for other researchers to perform their own sound file calibration for the purpose of sound therapy intervention. In this particular paper, the Audacity® software was used, and six sound files were calibrated: BBN, three BBN-like nature sounds (rain, ocean, waterfall), as well as two Quranic chapters, *Al-Fatihah* and *Yasin*.

MATERIALS AND METHODS

The aim of sound calibration is to ensure that the output of the sound transducer achieves the desired level.[20] To the best of our knowledge, no detailed guidelines on sound file calibration have been published. Thus, the methods of calibrating the sound file in this study was adapted from the procedures used in audiometric calibration for air conduction

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stimulus, as well as from previous experiences of one of the authors in calibrating Schroeder harmonic complexes sound.[20-22]

Sound file acquisition
The three nature sound files as well as the BBN file were downloaded from the Sound Bible website (www.soundbible.com), which provides free sound files as uploaded by various users. All sound files are in the Waveform Audio File Format (WAVE/WAV file). The Quranic recitations were downloaded from YouTube (www.youtube.com) and converted to the WAV format via the Online Video Converter website (www.onlinevideoconverter.com).

The length of the sound files are as follows: 1) BBN: 59 seconds, 2) ocean: 47 seconds, 3) rain: 33 seconds, 4) waterfall: 26 seconds, 5) A-Fatihah: 52 seconds, and 6) Yasin: 12 minutes and one second.

Intensity levels
All sound files were calibrated at intensity levels 45, 50, 55, 60, 65, 70, 75, and 80dBA.

Materials and instruments
The following instrumentations are among those recommended in order to carry out a sound calibration: a sound level meter (SLM), a two-cc or six-cc coupler, an acoustic calibrator, and a weight to place on top of the headphones during the calibration process.[22] For our specific sound file calibration purposes, we also required an external sound card (to bypass the laptop's sound card, so that the output from the headphones would remain constant even if different laptops are used in the future), and an audio editing software.

The following are the specific models used in our calibration process: TSI Quest Technologies Inc. (Shoreview, Minnesota, USA) earphone coupler (model EC-SA), 3M (Saint Paul, Minnesota, USA) SoundPro Class 1 1/3 Octave RTA sound level meter (SLM), Sennheiser (Wedemark, Germany) HD280 Pro headphones, Creative Technology (Jurong East, Singapore) Sound Blaster X-Fi Surround 5.1 Pro sound card, Audacity® (Pittsburgh, Pennsylvania, USA) software version 2.2.0, and TSI Quest Technologies Inc. (Shoreview, Minnesota, USA) audiometric calibration stand (model AS-1550).

Calibration setup
The calibration process was done in a sound treated booth with the ambient noise of 33.0dBA, which did not exceed the recommended ambient noise by the British Society of Audiology.[23] The sound files were played continuously from start to finish via the Audacity® software version 2.2.0 on an Acer Aspire E 14 laptop. The laptop was connected to the Sound Blaster X-Fi Surround 5.1 Pro sound card, and then the Sennheiser HD280 Pro headphones were plugged into the sound card. Fig. 1a) and 1b) show the equipment setup.

The earphone coupler used to calibrate the sound files was connected to the Type One SLM, and was fixed onto the audiometric calibration stand. One headphone was placed over the earphone coupler and a metal weight placed on top of it to secure its position.

Calibration steps
The calibration process began with recording and noting down the intensity levels of the unedited sound files; then, the appropriate amplification values were applied via the Audacity® software to achieve the desired levels (45, 50, 55, 60, 65, 70, 75, and 80dBA). The following is the step-by-step procedure taken to calibrate a BBN audio file to achieve the desired intensity levels. The same steps can be taken to calibrate other types of sound files.

Step One: The output from the right side of the headphone was muted in order to prevent the it from interfering with the calibration process of the left side of the headphone. To do this, the output on the right headphone was muted by going to the advanced settings of the sound card software (the Creative Entertainment Console software).

Step Two: The volume dial on the sound card was turned to the maximum level (100%) throughout the whole calibration process; this was to ensure that the SLM recorded the sound level at maximum output. The desired sound file was opened on the the Audacity® software. Fig. 2 a) shows the display on the Audacity® software once the sound file has been opened. Once opened, the software would display two waveforms: the one on top represents the output of the left channel, while the one on the bottom represents the output of the right channel.
Step Three: The SLM measurement started simultaneously with the start of the audio file, which was played using the sound generator software (in our case, the Audacity® software) (Fig. 2b). The SLM measurement was stopped only when the entire audio file had been played from start to finish (Fig. 2c). This way, the duration of the SLM measurement would accurately follow the actual length of the audio file, so that the long-term average of the sound pressure level over time (LAseq) could be obtained.

Step Four: The readings on the SLM were noted down, specifically the long-term average of the sound pressure level over the time of recording (LAseq) value (in dBA), the maximum intensity level (dBA), as well as the intensity levels (dBA) at frequencies 16Hz, 31.5Hz, 63Hz, 125Hz, 250Hz, 500Hz, 1000Hz, 2000Hz, 4000Hz, 8000Hz, and 16,000Hz.

Step Five: After noting down the intensity level displayed on the SLM for the unedited sound file (in our case, the LAseq reading was 87.3dBA for the unedited BBN sound file), the sound file was saved as *'BBN_unedited.wav'* file.

Step Six: Now, the intensity of the sound file can be edited to reach the desired level by applying an amplification or reduction effect (depending on whether the original audio file intensity is lower or higher than the desired intensity) on the audio file using the sound generator software. In the case of Audacity®, this was done by using the *'Amplification'* effect, which was applied in order to reach the first targeted intensity of 80dBA [refer to Fig. 2d) and 2e)]. From our observation, a dB change made in the Audacity® software is linear (i.e., increasing 5dB in the Audacity® software would result in an increase of 5dB output of the sound measured by SLM). Thus, the value of -7.3dB (to compensate the 87.3dBA

Table I: Amplification values applied (in dB) via the Audacity® software for the long-term average (LAseq) reading on the sound level meter (SLM) to reach the targeted intensity levels of 45, 50, 55, 60, 65, 70, 75, and 80 dBA for the left headphone

Sound file	Unedited sound file intensity recorded by SLM (dBA)	Audacity amplification value applied to unedited sound file sound file (dB)	Long-term average, LAseq, recorded by SLM after amplification (dBA)	Maximum sound pressure level, LAsmax, after amplification (dBA)	Long-term average (LAseq) for specific frequencies (Hz)										
					16	31.5	63	125	250	500	1000	2000	4000	8000	16,000
Broadband noise	87.3	-7.3	80.0	80.3	9.9	18.8	34.0	43.8	56.2	68.3	67.3	73.4	77.7	67.6	58.7
		-12.3	75.0	75.3	10.0	15.7	29.3	39.0	51.2	63.3	62.3	68.4	72.7	62.6	53.7
		-17.3	70.0	70.1	10.1	13.8	25.2	34.9	46.2	58.2	57.2	63.2	67.5	57.4	48.5
		-22.3	65.0	65.1	9.3	12.3	21.8	30.5	41.5	53.3	52.2	58.2	62.5	52.3	43.4
		-27.3	60.0	60.3	9.2	13.0	20.9	30.3	37.6	48.5	47.4	53.4	57.7	47.5	38.6
		-32.3	55.0	57.6	8.8	13.5	20.9	33.7	39.0	44.9	42.4	48.3	52.6	42.4	33.5
		-37.3	50.0	54.5	9.1	13.2	20.1	33.0	36.4	41.3	37.3	43.3	47.5	37.4	28.4
		-42.3	45.0	54.5	9.1	13.2	21.2	33.4	35.5	37.5	32.2	37.9	42.1	32.1	23.2
Al-Fatihah	87.5	-7.5	80.0	80.0	84.2	10.2	12.3	19.8	49.3	68.2	75.9	70.4	68.6	72.6	57.1
		-12.5	75.0	75.1	79.2	9.8	13.7	20.3	44.4	63.3	71.0	65.5	63.6	67.6	52.1
		-17.5	70.0	74.9	10.1	12.9	21.2	40.2	59.0	66.9	61.4	59.6	63.5	47.1	34.1
		-22.5	65.0	69.8	8.3	13.2	19.6	35.5	54.1	61.8	56.3	54.4	58.3	42.5	29.3
		-27.5	60.0	64.8	10.1	11.8	19.7	31.1	49.1	56.7	51.3	49.4	53.3	37.4	24.3
		-32.5	55.0	59.8	9.5	11.7	19.6	28.5	44.3	51.8	46.2	44.3	48.2	32.2	19.5
		-37.5	50.0	54.7	9.6	12.2	19.4	27.6	39.6	46.8	41.1	39.3	43.1	27.3	16.2
		-42.5	45.0	55.3	10.2	12.6	19.5	27.8	37.9	43.0	37.1	34.0	37.2	22.7	14.7
Waterfall	87.6	-7.6	80.0	80.5	12.9	13	21.9	34.6	48.1	63.1	63.5	72.4	77.3	73.4	42.3
		-12.6	75.0	75.0	13.0	12.8	21.0	36.1	44.4	58.2	58.5	67.4	72.3	68.4	37.4
		-17.6	70.0	70.5	12.9	13.2	21.3	41	42.5	53.3	53.5	62.4	67.3	63.4	32.4
		-22.6	65.0	65.5	11.7	12.8	20.4	37.6	39.8	48.2	48.5	57.4	62.3	58.4	27.4
		-27.6	60.0	61.0	11.5	12.4	20.6	36.5	36.4	43.5	43.5	52.3	57.2	53.3	22.5
		-32.6	55.0	56.7	11.4	12.4	20	34.2	33	39	38.4	47.2	52.1	48.2	17.3
		-37.6	50.0	52.7	12.2	12.6	20.8	28.6	35.9	37.4	33.4	42.1	47	43.1	14.3
		-42.6	45.0	50.4	12.5	12.4	20.9	30.3	33.6	35.1	28.4	36.8	41.7	37.8	14.3
Ocean waves	86.5	-6.5	80.0	85.6	10.0	16.6	36.4	54.4	70.9	76.6	71.6	70.3	72.2	52.0	33.1
		-11.5	75.0	80.7	10.8	14.3	31.6	49.4	66.0	71.7	66.6	65.3	67.2	47.0	28.1
		-16.5	70.0	75.7	11.0	15.2	27.7	44.5	61.0	66.7	61.6	60.3	62.2	42.0	23.2
		-21.5	65.0	70.7	11.0	13.2	24.1	39.6	55.9	61.7	56.6	55.3	57.2	37.1	18.7
		-26.5	60.0	65.7	12.0	13.9	22.5	35.4	50.9	56.7	51.6	50.3	52.2	32.1	15.1
		-31.5	55.0	60.7	11.7	14.0	21.5	31.7	46.0	51.7	46.6	45.3	47.2	27.4	14.3
		-36.5	50.0	55.7	11.6	13.8	21.5	28.5	41.2	46.8	41.5	40.3	42.2	23.2	14.3
		-41.5	45.0	54.4	12.5	14.4	22.0	37.2	38.6	42.0	36.5	35.4	37.2	20.8	14.3
Rain	86.9	-6.9	80.0	81.5	12.5	14.9	30.1	43.4	50.2	59.7	60.7	71.5	78.5	69.6	59.3
		-11.9	75.0	76.9	11.9	13.3	26.2	38.4	45.2	54.7	55.7	66.4	73.5	64.5	54.2
		-16.9	70.0	71.2	12.3	12.9	23.3	38.1	41.5	49.7	50.6	61.2	68.2	59.2	48.9
		-21.9	65.0	66.6	12.4	13.7	22.1	31.9	38.5	45.8	46.0	56.6	63.6	54.5	44.3
		-26.9	60.0	64.1	12.5	15.7	22.2	38.7	42.4	48.2	41.3	51.6	58.5	49.5	39.2
		-31.9	55.0	56.6	12.1	15.5	23.9	36.5	37.5	38.8	36.0	46.5	53.5	44.4	34.2
		-36.9	50.0	57.9	12.7	13.0	20.7	36.5	39.3	40.1	31.1	41.4	48.3	39.3	29.0
		-41.9	45.0	48.0	14.0	13.0	20.7	26.5	31.1	31.5	26.3	36.1	43.0	34.1	23.8
Yasin	100.3	-20.3	80.0	90.8	9.9	15.5	22.3	44.4	62.5	76.9	69.4	71.4	73.3	53.3	42.9
		-25.3	75.0	80.9	9.5	15.1	21.3	36.9	57.5	71.9	65.0	66.6	68.3	48.9	38.9
		-30.3	70.0	75.9	6.1	11.4	20.0	34.4	52.0	66.6	59.4	61.1	63.2	43.1	32.5
		-35.3	65.0	70.9	6.5	11.5	19.9	29.1	47.3	61.0	53.9	55.4	58.2	37.3	25.8
		-40.3	60.0	65.8	6.9	11.4	19.3	24.1	41.9	56.5	49.4	51.2	53.1	33.1	22.4
		-45.3	55.0	60.8	7.4	11.6	19.6	39.4	41.8	51.7	43.9	45.3	48.1	27.8	17.4
		-50.3	50.0	55.7	7.2	12.2	19.2	24.5	33.4	46.1	38.8	40.2	43.0	23.5	15.0
		-55.3	45.0	50.8	7.4	12.5	20.0	26.3	37.7	44.6	34.9	35.7	37.8	20.4	14.4

a.

b.

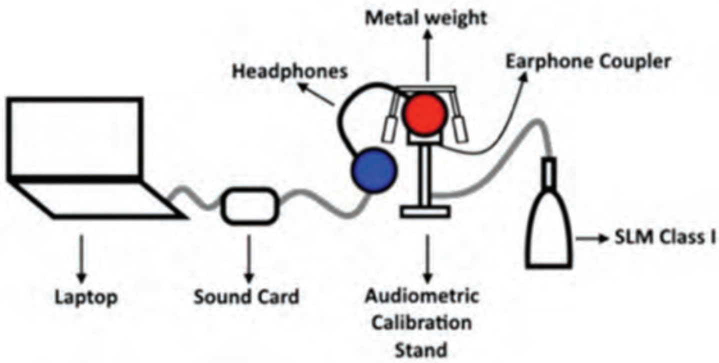

Fig. 1: a) The equipment setup. b) A simplified diagram of the equipment setup.

measured in step five) was entered to adjust the magnitude of the sound file to the targeted level (80dBA). Fig. 2e) and 2f) illustrate this step.

Step Seven: Once the amplification value has been applied to the sound file, Step Three was repeated to record the intensity of the edited sound file on the SLM. This step is conducted to ensure the measured level of the modified sound file (in Step Six) is actually meeting the target level. For this particular step, the SLM reading after the application of the *'Amplification'* effect was 80.0dBA. Apart from the overall LAseq reading, the LAseq values for specific frequencies were also recorded to give the idea of the energy distribution for each frequency components of the sound files.

Step Eight: The edited sound file was then exported and renamed appropriately (in our case, it was renamed as *'BBN_80dBA'*) [refer to Fig. 3a) and 3b)]. We recommend exporting the sound files as a 16-bit WAV format, due to two reasons: this format does not compress the sound file as much as the .mp3 format does, and the 16-bit format is fairly universal and can be found in music compact discs (CDs) as well as digital television sound system. The 16-bit format is also enough for capturing the sound properties of sound files for the purpose of sound therapy.

Steps Six was repeated to the *'BBN_unedited'* sound file in order to obtain the next targeted intensity level (75dBA). -12.3dB was entered into the *'Amplify'* box to achieve this targeted level. The sound file was then exported as a new .wav file and renamed *'BBN_75dBA.'* The same steps were repeated in order to obtain the sound file at the targeted levels of 70, 65, 60, 55, 50, and 45dBA.

Steps Three to Eight were repeated for the other five sound files. For this paper, only the left headphone was shown, should future researchers wish to calibrate both headphones, the steps described above can be repeated on the other headphone. All relevant values are displayed in Table I.

RESULTS

Table I shows the results of the calibration process for the left headphone. The name of the sound files, the intensity of the unedited sound file as recorded by the SLM (in dBA), the amount of amplification applied via the Audacity® software, the LAseq value (in dBA), as well as the LAseq values (in dBA) for specific frequencies are displayed for each sound type.

Based on Table I, it can be seen that for four sound files (BBN, waterfall, rain, and Yasin), the highest intensity occurred at 4,000Hz for all calibrated intensity levels. *Al-Fatihah* has the highest intensity at 1,000Hz at 75dBA and 80dBA, and at 4,000Hz for the rest of the intensity levels. The ocean waves

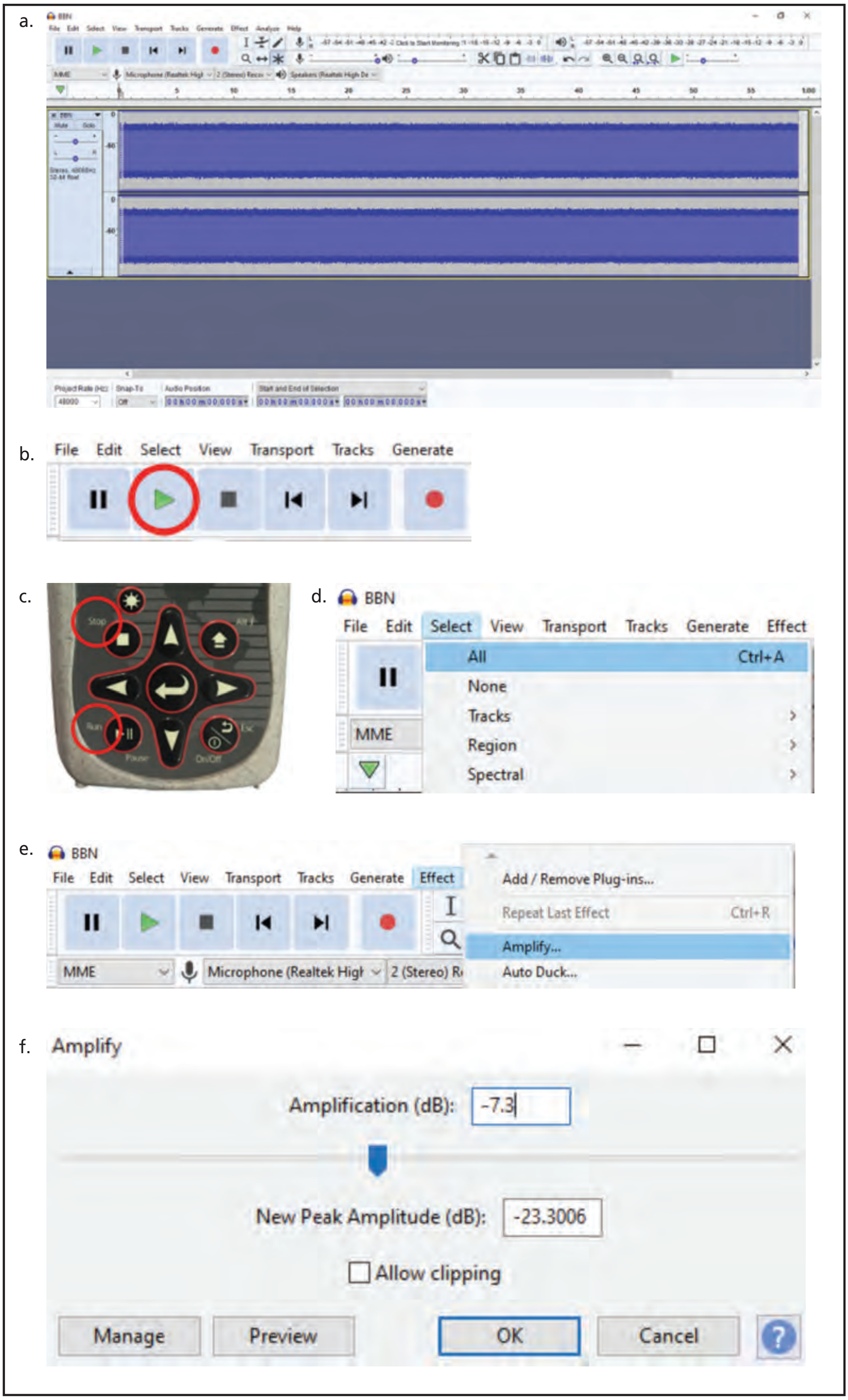

Fig. 2: a) The BBN sound file opened using the Audacity® software. b) The toolbar on the Audacity® software. The 'play' button is circled in red. c) The SLM 'run' and 'stop' buttons circled in red. d) Selecting the entirety of the waveform for the BBN sound file prior to applying the 'Amplifying' effect. e) Selecting the 'Amplify' effect on Audacity®. f) The 'Amplify' box; the value -7.3 dB was entered into the appropriate box.

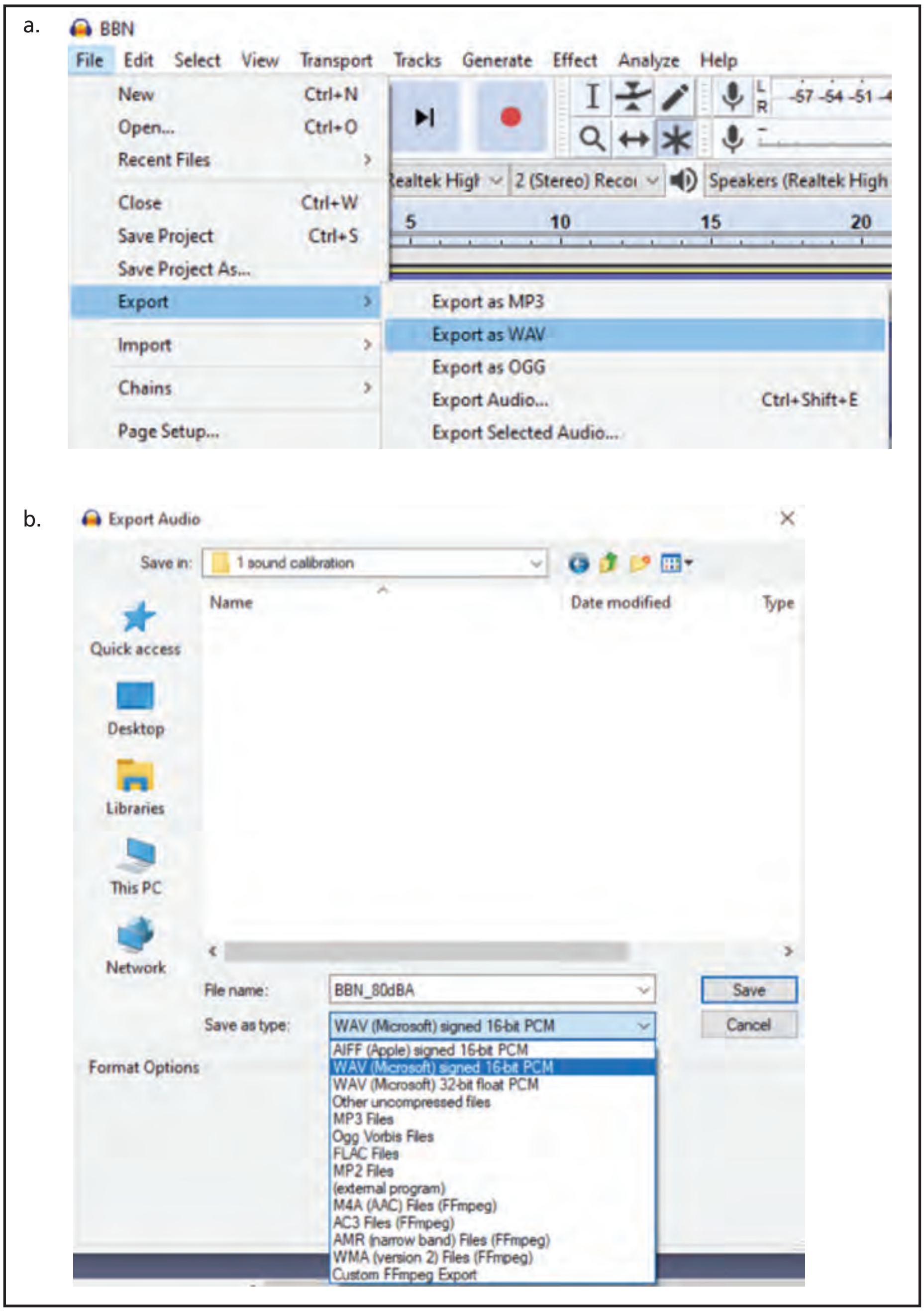

Fig. 3: a) The new sound file is exported as a .wav file. b) The new sound file is saved as 16-bit .wav file.

file, on the other hand, has the highest intensity occurring at 500Hz for all calibrated intensity levels.

Fig. 4 depicts the first 25 seconds of the waveforms of all six sound files at 80 dBA. Only the first 25 seconds of the files are shown as all the sound files are looped afterwards, except for Yasin, which is too long (12 minutes) for its waveform to be shown in its entirety. It can be see that BBN and waterfall have similar waveforms throughout the audio files; rain has a slight increase in energy at around three seconds into the audio file; ocean has the most fluctuation of energy throughout the audio file; both *Al-Fatihah* and *Yasin* have multiple fluctuations, as both are speech sounds.
When used in experiments, the different characteristics of these sound files may come in handy as they may help researchers explain the findings of the experiments.

DISCUSSION

In this discussion section, several caveats regarding the calibration process, as well as the implications of this current paper for the field of audiology are covered. Some limitations of the paper are also discussed.

Weighting scale: The sound files were calibrated using the A weighting, as it has a similar frequency response to that of the human ear, and is typically used in measuring the intensity of a sound.[24] The current paper measured the long-

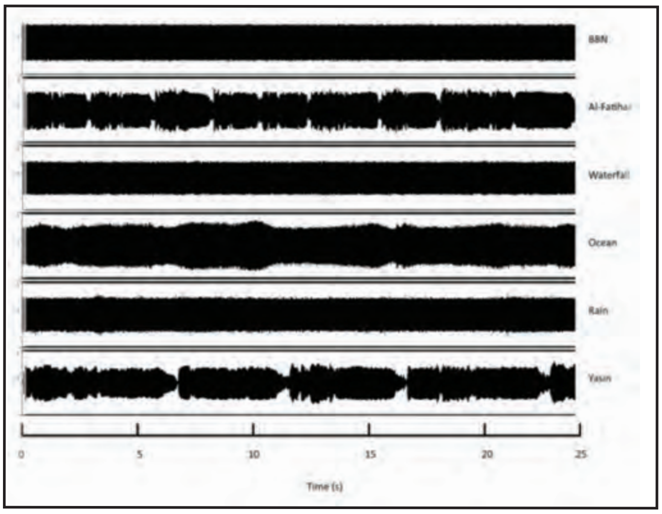

Fig. 4: The first 25 seconds of the waveforms of the six sound files.

Fig. 5: Switch off the 'threshold' option on the SLM in order to calibrate soft sounds.

term average of the sound pressure level (LAseq) instead of the peak value, as it is useful in specifying the average level of speaking voices (in this case, *Al-Fatihah* and *Yasin* recitations that contain wide ranges of fluctuations throughout the files) that span minutues, hours, or even days.[25]

Calibrating soft sounds

The aim of this study is to calibrate sounds from 45dBA and above. The ambient noise recorded in the sound-treated room was 33.0dBA which is fine for the targeted intensity levels; but could pose a problem when calibrating the sound files at lower levels. One step that could be taken when measuring sounds at lower levels is to turn off the 'threshold' setting in the SLM to allow any level of sound to be measured.[26] Fig. 5 shows the setting of the threshold in the SLM. Another precautionary step is to use the appropriate ear coupler adapter ring that could fit snugly around the headphone; otherwise, the sound might leak out and the SLM reading might not be accurate. By taking into account these factors, the first and second authors consequently did a separate calibration session at a different setting, and managed to calibrate one sound file to a level as low as 20dBA.

Using the unedited sound file

As a precautionary step, the authors had consistently applied the *'Amplification'* effect only on the original unedited sound file, and never on another already-edited sound file. This was done in order to avoid any possible distortions to the sound files as the calibration process continued on.

Implications

In this current paper, the six calibrated sounds have been incorporated in the development of 'Natural Acoustic' software (software used for sound therapy) which has been used in two studies for sound therapy purposes (ongoing study); i) investigated the effects of suppressor noises on the MOCS in normal hearing school-age children, and ii) investigated the effect of sound therapy on the working memory among normal hearing school-age children with suspected ADHD. The information obtained from the current calibration steps, such as the calibrated intensity level and the frequency specific energy distribution, may give an insight on the level and the frequency that are the most effective to activate the MOCS, as well as to optimize the working memory among the subjects. Future studies involving sound therapy, or even sound presentation to various populations, may use the calibrated sound files from the current paper, provided similar set up as in the current paper is also used (i.e., type of headphone and sound card).

Study limitations

In this study the calibration method has several limitations. Firstly, the calibrated intensity levels are only applicable for the Sennheiser HD 280 pro headphones. Therefore, future studies that aim to replicate our calibration methods will have to expect slight variations in their data if a different headphone model is used. Similarly, this study specifically used the Audacity ® software. There should be no restrictions if other researchers choose to use different free audio editing software other than Audacity®, but they should expect some differences in the calibration steps. Secondly, the current calibration method requires the use of a laptop or a computer and could not be performed with standalone music players such as MP3 devices. Lastly, the calibration was done in dB A, and the conversion to dB HL was not done in the current paper. This could be an area worth expanding into for future research in addition to the studies related to the reproducibility of the results using different devices and software mentioned earlier.

CONCLUSION

This paper has detailed out the procedure for calibrating sound files using free/open-source software for the purpose of sound therapy. The adjustments made using the software has achieved the targeted levels and were successfully used in other experiments. The calibration steps provided in this paper can be easily applied by other researchers for similar purposes, with precautions to be taken when calibrating at low levels.

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