ORIGINAL ARTICLE

Establishing transducers-dependent sensorineural acuity level normative data among young Malaysian adults

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ABSTRACT

Introduction: The sensorineural acuity level (SAL) test was developed as an alternative assessment to estimate bone conduction (BC) thresholds in cases where masking problems occur in pure tone audiometry (PTA). Nevertheless, prior to its clinical application, the respective SAL normative data must be made available. As such, the present study was carried out to establish SAL normative data using an insert earphone and two different commercially available bone transducers. Additionally, to determine the effect of earphone type on SAL test results, it was also of interest to compare the present study's findings with those of a previous study (that used a headphone to derive SAL normative data).

Materials and Methods: In this repeated-measures study, 40 Malaysian adults (aged 19–26 years) with normal hearing bilaterally (based on PTA results) were enrolled. They then underwent the SAL test based on the recommended protocol by Jerger and Tillman (1960). The SAL normative data for each ear were obtained by calculating the differences between air conduction (AC) thresholds in quiet and AC thresholds in noise by means of insert earphone, B71 and B81 bone vibrators.

Results: The SAL normative values were comparable between the ears ($p > 0.05$), and the data were pooled for subsequent analyses ($n = 80$ ears). Relative to B81 bone transducer, B71 bone vibrator produced statistically higher SAL normative data at all frequencies ($p < 0.05$). The SAL normative values established by the present study were statistically lower than those of the previous study (that utilised headphones) at most of frequencies tested ($p < 0.05$).

Conclusions: The SAL normative data produced by the two bone vibrators were significantly different. The SAL normative values were also affected by the type of earphone used. While conducting the SAL test on Malaysian patients, the information provided by this study can be useful to guide the respective clinicians in choosing the appropriate normative data.

KEYWORDS:
Sensorineural acuity level test; bone conduction; headphones; insert earphones; normative data

INTRODUCTION

Hearing loss is a common medical abnormality among babies, children and adults.[1-3] As such, significant advancements have been made in the field of diagnostic audiology aiming to provide accurate hearing diagnoses in clinical settings.[4-9] Some audiological tests are subjective in nature, i.e., the patients are required to give full cooperation during the testing (which can be challenging when assessing children). The availability of objective audiological tests would overcome the limitations of the subjective hearing assessments.[1] Moreover, by combining routine and advanced audiological tests, better clinical decisions can be made at the site of lesion testing. Identifying hearing problems in a timely manner is imperative so that appropriate treatment options can take place to achieve a better prognosis.[1,10]

The severity of hearing loss and the type of hearing loss are two important indicators in diagnosing hearing status.[1,11] Pure tone audiometry (PTA) has been regarded as the gold standard test for hearing diagnosis as both severity and type of hearing loss can be documented conveniently across speech frequencies.[1,4,11] In the PTA testing, headphones or insert earphones are used to determine air conduction (AC) thresholds that represent the severity of hearing loss. As reported elsewhere, normal hearing is defined if AC thresholds ≤ 20 dB HL.[1,4] That is, those with AC thresholds exceeding 20 dB HL are considered to have hearing loss. By placing a bone transducer on the mastoid area in the PTA testing, bone conduction (BC) thresholds are obtained. In this regard, it has been well demonstrated that the skull vibration mainly stimulates the inner ear and that the BC thresholds represent the status of cochlear.[1] By combining AC and BC thresholds, air-bone gaps (ABGs) represent the type of hearing loss.[1] Herein, significant ABGs (with normal BC thresholds) indicate the presence of conductive hearing loss (CHL, which occurs due to abnormalities affecting the outer and middle ears). On the other hand, if both AC and BC thresholds are abnormal with no significant ABGs, the type of hearing loss is known as sensorineural hearing loss (SNHL, which occurs due to damage affecting the inner ear). Meanwhile, when all parts of the ears are affected, it is known as mixed hearing loss (MHL). Getting the exact type of hearing loss is undoubtedly important as each type of hearing loss requires a specific treatment option.[1]

This article was accepted: 13 December 2023
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It is worth noting that when the pure tones at high-intensity levels are delivered by the insert earphones in the PTA testing, the skull may vibrate, and the BC pathway can be stimulated.[1] Consequently, the respective tones can be heard by the opposite ear. If the tested ear has poorer hearing than the non-tested ear, the hearing status recorded from the test ear will be invalid (i.e., better than it is supposed to be). This cross-hearing phenomenon must be addressed to achieve accurate hearing diagnoses. In this matter, masking procedure is typically carried out so that valid AC and BC thresholds can be obtained in the PTA testing.[1] That is, the masking noise will be delivered to the non-test ear (to eliminate cross-hearing) while presenting the tones to the test ear. To assist hearing healthcare professionals in deciding on the needs of masking, masking rules have been established.[1] Nevertheless, during the masking procedure, overmasking (i.e., providing "too much" masking noise) can occur, typically when assessing patients with large ABGs.[1] In this case, the exact BC thresholds cannot be measured, and the type of hearing loss is uncertain. As getting the accurate type of hearing loss is crucial, alternative solutions must be made available.

One of the feasible options to obtain valid BC thresholds (in the presence of overmasking) is to apply a sensorineural acuity level (SAL) test.[12-15] The procedure of this test has been well described in the literature.[13-15] It is worth mentioning that before this test can be applied in clinical settings, SAL normative data must be established first. To obtain this information, a group of healthy, normal-hearing participants is required. After the completion of PTA, a masking noise is delivered continuously at a maximum intensity level by the respective bone transducer that is placed on the forehead of the participant. While wearing headphones (or insert earphones) that deliver pure tones, he/she is asked to press the response button when the tones are heard (in the presence of masking noise). The AC thresholds in noise are then determined at specific frequencies. Subsequently, the SAL normative data are derived by computing the differences between AC thresholds in noise and AC thresholds provided by PTA at each of frequencies.[12,13] These data are then averaged across the participants to provide a better estimation.[14] To estimate the masked BC threshold of a hearing-impaired patient, a similar procedure is applied. That is, the AC threshold in noise at a specific frequency is obtained, and it is then subtracted from the respective SAL normative data (at a similar frequency). This value provides the amount of estimated ABG.[13] Herein, since the AC threshold in quiet is known (as provided by the PTA), the exact BC threshold can now be estimated.[12,13] Taken together, the following equation is used to calculate the estimated BC threshold at a specific frequency: Estimated BC = AC in quite – (AC in noise – SAL normative data).

Valid SAL normative data gathered from particular populations are essential for using the SAL test in clinical settings.[12,14] For example, the SAL normative data established among Malaysian adults were found to be different from those of Caucasian adults.[14] There has also been some variation in the methods employed by the previous studies in establishing the normative data for the SAL test. In particular, different types of earphones and bone transducers were used across the studies.[13-19] Sensibly, different study outcomes (as well as normative data) would be produced if the methods employed were different in some ways. Headphones and insert earphones have different characteristics, and they are used for specific applications.[1] Among others, headphones are useful when testing patients with no access to the AC pathway (e.g., canal atresia).[1] On the other hand, apart from having larger interaural attenuation values (relative to the headphones), insert earphones are recommended when assessing those with collapsed ear canals.[1,20] It is well known that in certain cases, when the headphones are placed against the pinna, the ear canal may partially or completely collapse.[1,20,21] This condition is more common among older adults and must be identified accordingly during the PTA testing to overcome the presence of "false" ABGs at high frequencies.[1,21,22] In clinical settings, Radioear B71 bone vibrator has been widely used in the PTA testing.[1,14] The newly designed Radioear B81 bone vibrator has been gaining an interest among clinicians and researchers nowadays due to its superior characteristics. Specifically, relative to the conventional B71 bone transducer, it was found to produce higher output levels with less vibrotactile responses and harmonic distortions at low frequencies.[23,24]

It is rather surprising that even though the interest in studying the clinical usefulness of the SAL test began in the 1950s, not many subsequent studies have been published since then. More recently, Awang and his colleagues conducted a study to compare the SAL normative data between two types of bone transducers.[14] In their study that utilised headphones, 42 Malaysian adults were tested, and the performance of commercially available Radioear B71 and B81 bone transducers was studied. As reported, the SAL normative data produced by the bone transducers were found to be statistically different at all test frequencies, implying the significant effect of the bone vibrator type on the SAL test results.[14] Herein, it is not known if a similar pattern would be observed if other types of transducers (e.g., insert earphones) are used.

Collectively, the present study was carried out to establish SAL normative data using insert earphones and two different bone transducers (i.e., B71 versus B81). Additionally, it was also of interest to compare the findings gathered from the present study and the study outcomes reported by Awang et al.[14] (that utilised headphones) to determine the effect of earphone type on the SAL normative data.

MATERIALS AND METHODS

Participants

In the present study that utilised a repeated-measures research design, 40 Malaysian young adults (aged 19–26 years) were enrolled. They were chosen randomly among students and staff members of the respective institution. They were all in good health and had no prior history of hearing problems. They were found to have a clear ear canal and an intact tympanic membrane on both sides, based on otoscopic and tympanometric assessments. According to the air conduction (AC) testing, their hearing was normal bilaterally, with hearing thresholds of 20 dB or less at

Table I: Mean and standard deviation (SD) of normative data for the sensorineural acuity level (SAL) test when tested with B71 and B81 bone transducers at specific frequencies (the respective statistical test results, i.e., p value and Cohen's effect size (d) are also shown)

Frequency (Hz)	Transducer	Mean ± SD (dB)	p value	Effect size (d)
250	B71	41.4 ± 7.3	< 0.001*	0.89
	B81	33.1 ± 7.6		
500	B71	53.2 ± 8.8	< 0.001*	0.94
	B81	44.8 ± 7.3		
1000	B71	62.9 ± 7.1	< 0.001*	0.63
	B81	57.0 ± 8.2		
2000	B71	60.3 ± 10.0	< 0.001*	0.76
	B81	51.4 ± 8.5		
4000	B71	58.0 ± 9.4	< 0.001*	0.90
	B81	50.1 ± 8.3		

*Significance at p < 0.05.

Table II: The respective statistical test results when the data of the present study (that used insert earphones) are compared with the findings reported by Awang et al. (2021) that employed headphones for establishing the normative data for the sensorineural acuity level (SAL) test

Frequency (Hz)	Transducer	Mean ± SD (dB)		p value
		Present study	Awang et al. study	
250	B71	41.4 ± 7.3	46.3 ± 8.2	< 0.001*
	B81	33.1 ± 7.6	38.5 ± 9.1	< 0.001*
500	B71	53.2 ± 8.8	61.1 ± 7.2	< 0.001*
	B81	44.8 ± 7.3	51.7 ± 8.1	< 0.001*
1000	B71	62.9 ± 7.1	66.5 ± 8.0	< 0.001*
	B81	57.0 ± 8.2	59.4 ± 7.2	0.010*
2000	B71	60.3 ± 10.0	60.0 ± 8.7	0.824
	B81	51.4 ± 8.5	54.9 ± 9.8	< 0.001*
4000	B71	58.0 ± 9.2	58.4 ± 9.8	0.706
	B81	50.1 ± 8.3	50.0 ± 8.1	0.936

*Significance at p < 0.05.

frequencies ranging from 250 to 8000 Hz. Each participant signed a consent form prior to the data collection, and the study was approved by the respective institutional review board, which is in line with the 1975 Declaration of Helsinki and its later amendments.

Test Procedure

The PTA and SAL tests were conducted using a two-channel audiometer (GSI 61, Grason-Stadler Inc., USA) in a dedicated soundproof room within the Audiology Clinic, University Hospital. Prior to the assessments, adequate instructions were given to each of the participants. The PTA testing was conducted based on the standard protocol, and AC and BC thresholds were obtained according to the established Hughson–Westlake method.[1] Insert earphones (ER-3A, Etymotic Research, Illinois, USA) were used to measure AC thresholds (from 250 to 8000 Hz), while both B71 and B81 transducers were employed to determine BC thresholds (from 250 to 4000 Hz) for both ears. In the BC testing, the bone transducer was placed on the mastoid of each ear, and the order in which transducer was to be used was randomised across the participants to avoid any potential bias. Each participant was asked to press the response button whenever tones were heard (regardless of the loudness of tones). Only the AC thresholds in quiet obtained in the PTA testing would be used subsequently to derive the SAL normative data.

Following the PTA testing, the SAL test was carried out using the procedure recommended by Jerger and Tillman.[13] In particular, insert earphones were inserted into each ear while the bone vibrator was placed on the forehead (Fig. 1). A narrowband noise of masking at a maximum intensity level was delivered continuously via the bone transducer, while a pure tone was presented to one ear through the insert earphones. The participants were told to ignore the noise and only press the response button when they heard the tone. For each ear, the AC thresholds in noise at frequencies of 250, 500, 1000, 2000, and 4000 Hz were measured. The differences between AC thresholds in quiet (by PTA) and AC thresholds in noise (by SAL test) were used to calculate the SAL normative data. Likewise, to avoid potential bias, the order in which the transducers were to be used was randomised across the participants.

The SAL normative data at each frequency were gathered from all participants. Mean, standard deviation (SD) and percentage were utilised to express the data as applicable. The Shapiro–Wilk normality test revealed that the data for each ear were normally distributed (p > 0.05). As such, the paired t-test was used to compare the SAL normative data between the left and right ears. This analysis was again used to compare the SAL normative data between B71 and B81 bone transducers at each frequency. On the other hand, the one-sample t-test was used to compare the data from the present study with those published by Awang et al.[14] The

Fig. 1: The sensorineural acuity level (SAL) test procedure of a representative subject.

statistical significance level was set at $p < 0.05$. Additionally, to support the results of the hypothesis testing, Cohen's effect size (d) was measured. Herein, d = 0.2, d = 0.5 and d = 0.8 represent small, medium and large effect sizes, respectively.[25] All data were analysed using the JASP statistical software (version 0.17.1, University of Amsterdam, Netherlands).

RESULTS

In terms of ethnicity, Malay adults made up 75.0% of the total participants, followed by Chinese (15.0%) and other ethnic groups (10.0%). Their mean age was 22.9 ± 1.2 years, and the majority of them were females (65.0%).

The SAL test was successfully completed by each of the participants. The data for left and right ears were then combined (a total of 80 ears) for further analysis because it was determined that the SAL normative data did not statistically differ between the left and right ears at all tested frequencies ($p > 0.05$ using the paired t-test).

Table I shows mean, SD and statistical results when the SAL normative data were compared between the two bone transducers (n = 80 ears). As clearly revealed, the B71 bone transducer produced statistically higher SAL normative data relative to the B81 bone vibrator at all frequencies ($p < 0.05$). These findings were in line with the moderate to large effect sizes (d = 0.63–0.94).

Recall that the present study employed insert earphones and the respective bone transducers to generate the SAL normative data among healthy young adults. As stated earlier, the present study also aimed to compare the SAL normative data gathered from the present study and the findings reported by Awang et al.[14] that employed headphones for establishing their SAL normative data. The results of this comparison are shown in Table II. The different performance between these transducers (insert earphones and headphones) was elaborated in the discussion section.

DISCUSSION

Even though the PTA testing has been used utilised widely in clinical practice, obtaining masked thresholds can be troublesome due to masking problems. The emergence of the SAL test has provided an alternative solution for estimating masked BC thresholds (so that the type of hearing loss can be confirmed). As previously mentioned, the literature on the SAL test is currently limited, and more studies are warranted to further unveil the diagnostic usefulness of this test.

In the PTA testing, the commercially available audiometers are typically equipped with either Radioear B71 or B81 bone vibrators. The newly designed B81 bone transducer was developed with the intention of overcoming the limitations of the B71 bone transducer.[23,24] In the present study, the SAL normative data were established by means of insert earphones and the two bone transducers. As revealed, the SAL normative values produced by the B71 bone transducer were significantly higher than those of the B81 bone vibrator. Given the different designs and characteristics of the bone transducers, these findings were rather sensible. Similar outcomes were reported by Awang and his colleagues when comparing the performance of B71 and B81 bone vibrators in the SAL test.[14] They proposed that the differences in the SAL normative values might be due to several reasons including the increased sensation of vibrotactile of the B71 bone transducer. The different capabilities of the two transducers in delivering masking noise at maximum levels were also proposed as the reason for the discrepancies in the SAL normative data.[14] Even though these notions appear to be reasonable, future research is needed to further shed light on this issue. In this regard, performing the SAL test on adults with severe SNHL (with poor BC thresholds and enhanced vibrotactile sensations) can be advantageous to understand the mechanism of SAL test when tested with the two bone transducers.

To determine the possible effect of the earphone type on the SAL normative values, the present study's findings were compared with the data reported by Awang et al.[14] As shown in Table II, with the B71 bone vibrator, the SAL normative data were significantly lower in the present study than in the study by Awang et al.[14] at 250, 500 and 1000 Hz frequencies ($p < 0.05$). Whereas at 2000 and 4000 Hz, the SAL normative data between the studies were comparable ($p > 0.05$). Likewise, with the B81 bone transducer, the present study revealed statistically lower SAL normative data relative to the study by Awang et al.[14] at the majority of frequencies (i.e., 250 Hz, 500 Hz, 1000 Hz and 2000 Hz). At 4000 Hz, the SAL normative data between the two studies did not differ significantly with $t(79) = 0.081$, $p = 0.936$. This comparison was considered appropriate, as the methods employed by both studies were almost similar. Specifically, both studies were carried out among Malaysian participants with comparable sample sizes and age ranges (i.e., 42 adults aged 19–27 years in the study by Awang et al.[14]). Furthermore, both studies employed the similar SAL test procedure, i.e., based on the protocol recommended by Jerger and Tillman.[13]

It is worth stating that the data gathered from studies involving other ethnic groups (e.g., Caucasian adults) may not be appropriate to be compared.[14] Apart from methodological differences (e.g., different sample sizes, different types of earphones and bone transducers, etc.),[14,17,18] anatomical factors including head size and bone density may also contribute to the variation in the SAL normative data.[26-29] It was found that at most of the frequencies tested, the SAL normative data produced by the present study (with insert earphones) were statistically lower than those reported by Awang et al.[14] (that utilised headphones). Since both transducers were designed differently and for specific applications, the obtained results were somehow anticipated. Awang and his colleagues employed the Telephonics TDH-39 supra-aural headphones (that rest on the ear and do not completely enclose the ear) to derive the SAL normative values.[14] The insert earphones used in the present study consist of a tube that delivers pure tone signals through compressible earplugs that are placed in the ear canal. As mentioned before, this transducer is useful for assessing those with collapsed ear canals to avoid misdiagnosis of the type of hearing loss.[20-22] Of note, since the output of both transducers is calibrated in dB HL, AC and BC thresholds obtained in the PTA testing (by both transducers) should be comparable. In line with this, previous studies revealed that both transducers had similar intra-subject reliability and test–retest stability.[30,31] In this regard, the differences in the SAL normative data by the two transducers might be due to differences in AC thresholds in noise (obtained in the SAL test). That is, relative to headphones, less threshold shifts were observed (in the presence of noise given by the bone transducer) when insert earphones were used. As shown in Table II, the mean difference between the earphones can be as large as 7.9 dB (for B71 bone vibrator at 500 Hz). This difference can be considered clinically large (i.e., more than ± 5 dB),[1] and the accuracy of the SAL test can be affected. Further studies are therefore warranted to determine which transducer is more accurate in predicting BC thresholds when testing hearing-impaired patients.

The present study had several limitations. Firstly, the sample size used was modest (n = 40), and perhaps better study results would be obtained if more participants were recruited. Nevertheless, recall that the data for left and right ears were pooled (n = 80 ears) as an effort to enhance the statistical power. Furthermore, the effect size analysis was also employed to support the p values. As reported elsewhere, unlike the p value approach, the effect size analysis provides the magnitude of difference between the groups of interest and is less affected by the sample size.[32,33] In fact, the hypothesis testing and effect size results were found to be consistent with each other, indicating that the desired study outcomes had been achieved. Secondly, the SAL normative data were gathered only from a group of healthy young adults. Obtaining similar data from other age groups should be the next step. Lastly, only those with normal hearing were enrolled in the present study. As such, further studies involving hearing-impaired groups are beneficial to verify the appropriateness of the SAL normative data obtained in the present study.

CONCLUSIONS

The SAL test is particularly useful to determine exact BC thresholds (to avoid misdiagnosis) in cases where the masking procedure fails to do so. Nevertheless, prior to its application, the SAL normative data must be made available. In the present study, insert earphones and two different bone transducers were employed to establish the respective SAL normative data. The SAL normative data produced by the commercially available Radioear B71 and B81 bone transducers were found to be statistically different at all frequencies. Additionally, insert earphones and headphones produced significantly different SAL normative data at the majority of frequencies. The information provided by the present study can be useful to hearing healthcare practitioners in determining which SAL normative data to be applied in clinical settings.

ACKNOWLEDGEMENT

This project was funded by the Short-Term Grant (Universiti Sains Malaysia) with Project Code: 304/PPSK/6315335.

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