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IMPACT OF BACKGROUND NOISE ON WIDEBAND ABSORBANCE FINDINGS

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Contributions:
A Study design/planning
B Data collection/entry
C Data analysis/statistics
D Data interpretation
E Preparation of manuscript
F Literature analysis/search
G Funds collection

Abstract

Introduction: Measuring wideband absorbance (WBA) in noisy environments can potentially lead to inaccurate results due to noise contamination. However, research investigating the effect of background noise on WBA is scant. This study aimed to evaluate the effects of increasing levels of background noise on WBA results.

Material and methods: A non-randomised, cross-sectional, repeated measures design was used. Participants were 50 adults who passed otoscopic examination, pure tone audiometry, and tympanometry screening in their right ear. WBA was measured using an Interacoustics Titan immittance device under four broadband noise conditions: quiet (no applied noise), 55 dBA, 65 dBA, and 75 dBA.

Results: Increasing noise levels were associated with decreasing mean absorbance at 0.25–2.5 kHz with the greatest difference of 0.049 (normalised difference of 7.76%) found between the quiet and 75 dBA noise conditions at 1 kHz. Conversely, increasing noise levels were associated with increasing mean absorbance at high frequencies (4–8 kHz) with the greatest difference of 0.035 (normalised difference of 12.9%) found between the quiet and 75 dBA noise conditions at 5 kHz.

Conclusions: The present study found statistically significant differences in WBA findings with increasing broadband noise levels of up to 75 dBA. However, the WBA differences were too small to be of clinical significance.

Keywords: wideband absorbance • background noise • adults

WPŁYW SZUMU TŁA NA WYNIKI POMIARÓW ABSORBANCJI SZEROKOPASMOWEJ

Streszczenie

Wprowadzenie: Pomiar absorbancji szerokopasmowej (WBA) w hałaśliwym otoczeniu może potencjalnie prowadzić do niedokładnych wyników z powodu zanieczyszczenia hałasem. Jednak badania analizujące wpływ szumu tła na WBA są nieliczne. Niniejsze badanie miało na celu ocenę wpływu rosnącego poziomu szumu tła na wyniki WBA.

Materiał i metody: Zastosowano nierandomizowane, przekrojowe badania powtarzanych pomiarów. Uczestnikami było 50 dorosłych osób, którym wykonano następujące badania: otoskopię, audiometrię tonalną i tympanometrię w prawym uchu. WBA mierzono za pomocą urządzenia Interacoustics Titan przy czterech poziomach hałasu szerokopasmowego: cichym (bez zastosowanego hałasu), 55 dBA, 65 dBA i 75 dBA.

Wyniki: Wzrost poziomu hałasu wiązał się ze spadkiem średniej absorbancji na częstotliwościach 0,25–2,5 kHz, przy czym największą różnicę, wynoszącą 0,049 (znormalizowana różnica 7,76%), stwierdzono pomiędzy poziomem cichym i dla hałasu wynoszącego 75 dBA dla częstotliwości 1 kHz. I odwrotnie, wzrost poziomu hałasu wiązał się ze wzrostem średniej absorbancji na wysokich częstotliwościach (4–8 kHz) z największą różnicą 0,035 (znormalizowana różnica 12,9%) stwierdzoną między poziomem cichym i dla hałasu wynoszącego 75 dBA dla częstotliwości 5 kHz.

Wnioski: W niniejszym badaniu stwierdzono różnice istotne statystycznie w wynikach WBA wraz ze wzrostem poziomu hałasu szerokopasmowego do 75 dBA. Różnice WBA były jednak zbyt małe, aby mieć znaczenie kliniczne.

Słowa kluczowe: absorbancja szerokopasmowa • szum tła • dorośli

Key for abbreviations	
NICU	neonatal intensive care unit
nil	nothing
pers comm	personal communication
SNR	signal-to-noise ratio
WBA	wideband absorbance
WBR	wideband reflectance

Introduction

Wideband absorbance (WBA) is an emerging clinical tool utilised to detect outer- and middle-ear dysfunctions [1]. Essentially, it is used to evaluate the function of the outer and middle ears by measuring the proportion of acoustic energy absorbed by the middle ear across the frequency spectrum (200–8000 Hz) [2]. Middle-ear disorders such as otitis media with effusion, otosclerosis, tympanic-membrane perforations, cholesteatoma, and ossicular-chain disorders disrupt the dynamics of the middle ear, which, in turn, impacts how sound is absorbed by the middle ear [3–5]. Merchant et al. and Masud et al. suggest that WBA can also be utilised as a fast and non-invasive screening tool to detect semicircular canal dehiscence [6–7].

Measuring wideband absorbance in noisy environments can potentially lead to inaccurate results due to noise contamination. Liu et al. [8] remarked that the accuracy of WBA measurements depends on the signal-to-noise ratio (SNR) of the measurement. They raised concerns that transient physiological noise produced by the subject, or noise from the environment, may be recorded by the probe microphone and thus reduce the SNR, particularly at low frequencies. However, the authors did not systematically investigate the impact of these types of noise on WBA.

In pediatric applications of wideband acoustic immittance measures, Hunter and colleagues reported that noise can lead to unreliable results [9]. The authors stressed the importance of having a quiet child in a quiet environment in order to achieve accurate and reliable WBA results. However, there are situations where WBA is measured in less-than-ideal noisy environments. For example, Shahnaz measured WBA in neonates cared for in a neonatal intensive care unit (NICU) [10]. He reported that high ambient noise levels in the NICU of up to 65 dBA produced unreliable WBA results at frequencies below 400 Hz. He then discarded the WBA data below 400 Hz and analysed the data between 450 and 6000 Hz, because in that frequency range the WBA results were reliable and had clearly identifiable peaks and troughs.

Gouws and colleagues investigated the use of wideband reflectance (where the WBR is defined as 1 – WBA) with preterm neonates within a noisy NICU environment [11]. They found that ambient and physiological noise introduced large variability into the WBR data. Though the authors strove to maintain low noise levels during testing, they could not improve the SNR in their WBR measurements. They suggested that excessive noise could have elevated the WBR values, mainly at low frequencies. However, they did not measure the ambient noise levels inside the NICU. Although previously reported wideband acoustic immittance measurements were affected by a combination of background and physiological noise in infants, it has not been demonstrated whether background noise contributes significantly to variability in WBA. The present study attempts to address this issue by examining the effect of different background noise levels on WBA obtained from normally-hearing adults, who have relatively low physiological noise compared to infants.

Material and methods

Ethical clearance for this study was obtained from the University of Queensland Health and Behavioural Sciences, Low and Negligible Risk Ethics Sub-Committee (approval number 2019000817). Participants were students at the University of Queensland and their friends. Written consent from all participants was obtained before testing began.

Research design

This study employed a non-randomised, cross-sectional, repeated-measures design. A Master of Audiology student (JP), who received intensive training from an experienced audiologist (JK) in conducting hearing tests including wideband absorbance measurements, conducted all assessments in a sound-treated booth with an ambient noise level of less than 30 dBA as measured using a Brüel & Kjær Type 2250 sound level meter.

Participants

Initially, 59 participants were recruited. To be included in the study, participants had to pass a battery of basic tests including otoscopy, pure-tone audiometry, and tympanometry in the right ear. The pass criteria for these tests are depicted in the test procedure section. Eventually, 50 adults (27 males, 23 females) were included in the study, within the age range of 18–46 years (mean age of 27.6 years). The remaining 9 adults did not meet the pass criteria and were excluded from the study.

Test procedure

Audiological assessments were conducted on the participant's right ear only. The test battery consisted of otoscopy, pure-tone audiometry, tympanometry, and wideband absorbance measures at ambient pressure (i.e., no external pressure was applied to the ear canal). Otoscopy was performed using a Welch Allyn otoscope to examine the ear canal and eardrum for signs of abnormalities.

Pure-tone audiometry was conducted using a GSI AudioStar Pro audiometer with Telephonics TDH-39 headphones. Air-conducted hearing thresholds at octave-band frequencies between 250 and 8000 Hz were obtained using a modified Hughson–Westlake procedure [12]. Bone-conducted hearing thresholds were assessed at octave-band frequencies between 500 and 4000 Hz using a Radio-ear B71 bone conductor. The pass criteria were: (1) all hearing thresholds must be ≤ 15 dB HL, and (2) air-bone gaps must be < 15 dB at all test frequencies [13].

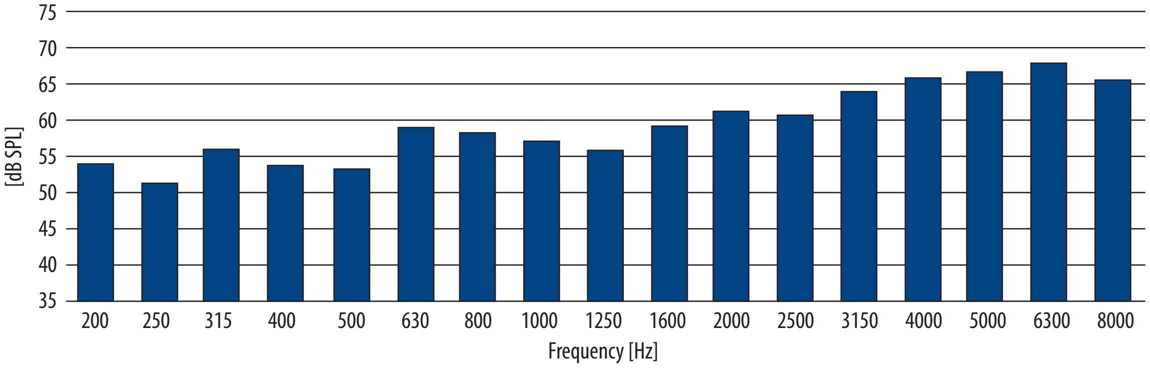

Figure 1. Spectrum of broadband noise at 75 dBA as measured at the ear position using a B&K Type 2250 sound level meter

Tympanometry was performed using an Interacoustics Titan immittance device connected to a laptop computer via the NOAH (ver. 4) software platform. Calibration was performed daily using a 2 cm^3 coupler. A suitably sized rubber probe tip was selected and fitted onto the probe before being placed in the participant's ear canal. During the test, a probe tone of 226 Hz was delivered to the ear at 85 dB SPL while the pressure was varied from +200 to –400 daPa at a rate of 400 daPa/s. A tympanogram was obtained of admittance (in mmho) against ear canal pressure (in daPa). The pass criterion was a single-peaked tympanogram with static admittance between 0.3 and 1.6 mmho, and tympanometric peak pressure between +50 and –100 daPa [14,15].

Testing WBA in quiet and noisy conditions

Participants were required to sit on a comfortable chair in a sound-treated booth, with their right ear facing a Dali 2b loudspeaker, which was situated 1 m from the ear (determined using a measuring tape). The WBA test was performed immediately after tympanometry without changing the probe seal. The test was initially performed in quiet (no applied noise). WBA measures were obtained using the same Interacoustics Titan device (IMP440/WBT440 impedance module). Testing began when the probe light turned green, indicating an adequate probe seal for testing. Measurements were obtained by recording acoustic responses to wideband clicks presented at 65 dB nHL at a rate of 21.5 clicks/s under ambient pressure conditions (i.e., no pressure applied to the ear canal). WBA was measured at 1/24-octave-band frequencies between 226 and 8000 Hz, where the value of each point was calculated based on the average response of 32 clicks. During the WBA test, the tester checked for any probe leak which would result in increased absorbance (> 0.29) at low frequencies (250–500 Hz) [16]. If acoustic leakage was suspected, the probe was removed, then re-inserted to ensure an adequate seal was obtained, and the test was repeated.

For testing in noise, a Dali 2b loudspeaker connected to a GSI Audiostar clinical audiometer played broadband (white) noise to the participant's right ear, which was situated 1 m from the loudspeaker. White noise was used because it has an equivalent acoustic spectrum to the WBA click stimuli, allowing changes in absorbance across the entire frequency range (200–8000 Hz) to be observed. Noise levels of 55 dBA, 65 dBA, and 75 dBA were used to investigate the impact of background noise on WBA. The noise levels were measured using a Brüel and Kjær Type 2250 sound level meter, which was mounted on a tripod at the place previously occupied by the participant's right ear, with the microphone directed to the loudspeaker (0° azimuth). **Figure 1** shows the spectrum of the broadband noise at 75 dBA as measured using the sound level meter. The spectrum was consistent with the loudspeaker's documented frequency response between 200 and 8000 Hz. The spectrum shows a moderate rising slope as a function of frequency.

Prior to WBA testing in background noise, a foam ear plug was inserted into the participant's left ear to avoid a possible noise suppression effect on the measurement [17]. WBA testing in noise began at 55 dBA and the entire test procedure was then repeated with noise levels of 65 dBA and 75 dBA. This order of testing with increasing background noise level was adopted as there is presently no clear evidence of an order effect for noise levels on WBA measures.

Data analysis

WBA was measured as a function of frequency from 226 to 8000 Hz at 1/24-octave-band steps. For analysis, the WBA data were converted to 1/3-octave bands between 250 and 8000 Hz. Because the WBA data at 315 Hz, 5000 Hz, 6300 Hz, and 8000 Hz were not normally distributed, a square-root transformation was applied to these variables to achieve normality. The results of Shapiro–Wilk tests applied to all WBA data (transformed and non-transformed) indicated that they were normally distributed at all frequencies and noise conditions ($p > 0.05$). A repeated-measures analysis of variance (ANOVA) was applied to the data, with WBA being the dependent variable, and frequency, noise level, and gender being the independent variables. The Greenhouse and Geisser approach was used to compensate for the violation of compound symmetry and sphericity [18]. A significance level of 0.05 was used for all analyses.

Results

Figure 2 displays the mean WBA plotted against 1/3-octave-band frequencies between 250 and 8000 Hz for the

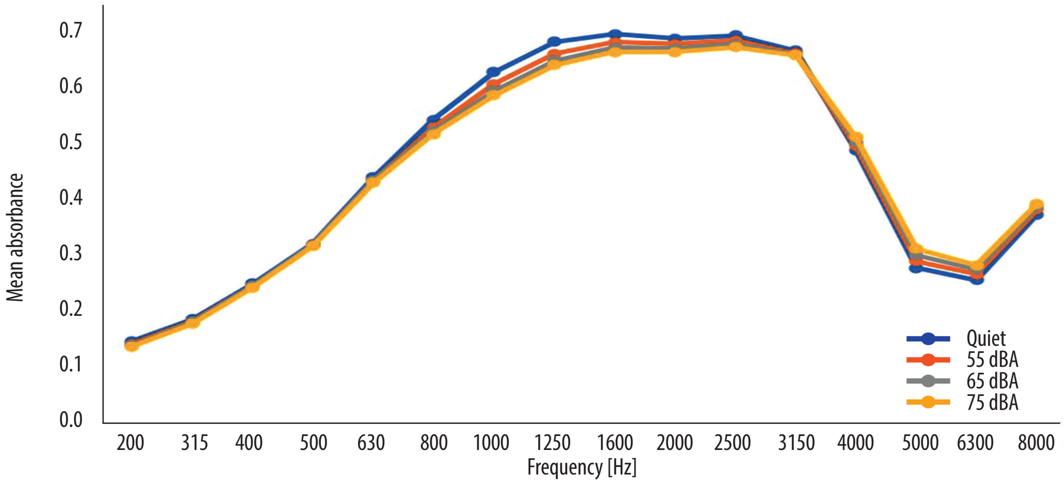

Figure 2. Mean WBA from 250 to 8000 Hz for four noise levels (quiet, 55 dBA, 65 dBA, and 75 dBA)

four noise levels (quiet, 55 dBA, 65 dBA, and 75 dBA). Mean WBA results at 250–630 Hz were about the same across all noise conditions. There was a trend of decreasing mean WBA with increasing noise levels at 800–3150 Hz. In contrast, an opposite trend was observed in which mean WBA increased with increasing noise levels at 4000–8000 Hz.

A repeated-measures ANOVA of the WBA data showed a significant frequency effect $F(1.58, 75.98) = 93.53$, $p < 0.001$; noise effect $F(1.25, 59.81) = 36.01$, $p < 0.001$; gender effect $F(1, 48) = 6.604$, $p = 0.013$, and frequency × noise interaction effect $F(2.84, 136.39) = 35.35$, $p < 0.001$. However, the frequency × gender $F(1.58, 75.98) = 1.18$, $p = 0.304$; noise × gender $F(1.25, 59.81) = 1.05$, $p = 0.326$, and frequency × noise × gender interaction effects $F(2.84, 136.39) = 0.864$, $p = 0.456$, were not significant.

Further ANOVA analyses were performed with WBA as the dependent variable and noise and gender as independent variables to determine the noise and gender effects at each frequency. As **Table 1** shows, noise had a significant effect on WBA at all frequencies ($p < 0.05$) except for 400 Hz, 500 Hz, and 630 Hz. Gender had a significant effect on WBA mainly at low frequencies. However, the noise × gender interaction effect was significant only at 5000 Hz $F(1.21, 58.10) = 3.909$, $p = 0.045$.

Table 2 shows the results of post-hoc pairwise comparisons with Bonferroni adjustments between the different noise conditions at each frequency. The results indicate significant differences in mean WBA between any two noise conditions at 800–2500 Hz and 4000–8000 Hz, with the greatest difference being between the quiet and 75 dBA conditions. The mean WBA in the quiet condition was greater than that in the 75 dBA noise condition between 250 and 3150 Hz, whereas an opposite trend was observed at 4000–8000 Hz. Difference in mean WBA between the quiet and 75 dBA noise condition varied between 0.009 and 0.049 at 250–3150 Hz, and from −0.021 to −0.035 at 4000–8000 Hz. The normalised difference – defined as (mean WBA in quiet – mean WBA in 75 dBA noise)/mean WBA in quiet × 100% – varied between 1.44 and 7.52% at 250–3150 Hz, and between −5.02 and −12.94% at 4000–8000 Hz.

Discussion

Effect of background noise on WBA

The primary aim of the present study was to investigate the effects of increasing levels of background noise on the WBA obtained from normal-hearing adults. The results showed significant differences in mean WBA across all frequencies, except for 400–630 Hz, as the background noise increased from 55 to 75 dBA. We observed a trend of decreasing mean WBA at 250–3125 Hz (excluding 400–630 Hz), and increasing mean WBA at 4000–8000 Hz, with increasing background noise levels of up to 75 dBA. This pattern of results is not expected because we would have expected mean WBA to decrease with increasing noise levels across most frequencies. The reason for the increase in mean absorbance at 4000–8000 Hz with increasing noise level is not clear. We speculate that during the measurements, sound waves reflected by the middle ear were recorded by the probe microphone and may have been contaminated by the high levels of broadband noise, leaking through the probe tube and eartip. Further research using lower noise levels (< 55 dBA) may be required to test this hypothesis.

Our experience measuring WBA in noisy conditions revealed that the WBA curve within the measurement software was unstable during the signal averaging process. The Interacoustics company (pers comm, 22 October, 2019) state that the WBA algorithm includes a noise rejection mechanism, whereby any click response that substantially deviates due to noise contamination is automatically discarded. Additionally, the clicks are high-pass filtered to remove low-frequency noise. The Titan WBA algorithm employs a synchronous-averaging approach using 1024-sample blocks. According to Interacoustics, steady-state broadband noise is averaged out, but this may require a long measurement time.

Table 1. Summary of ANOVA results showing the significance level of the effects of noise, gender, and their interaction on the WBA measurements

Frequency [Hz]	Noise	Gender	Noise × Gender
250	$p < 0.001$	$p = 0.005$	#
315	$p = 0.002$	$p = 0.010$	#
400	#	$p = 0.010$	#
500	#	$p = 0.006$	#
630	#	$p = 0.022$	#
800	$p < 0.001$	#	#
1000	$p < 0.001$	$p = 0.023$	#
1250	$p < 0.001$	#	#
1600	$p < 0.001$	#	#
2000	$p < 0.001$	$p = 0.035$	#
2500	$p < 0.001$	#	#
3150	$p < 0.001$	#	#
4000	$p < 0.001$	$p = 0.035$	#
5000	$p < 0.001$	#	$p = 0.045$
6300	$p < 0.001$	#	#
8000	$p < 0.001$	#	#

Note: # indicates not significant ($p > 0.05$)

Table 2. Summary of significant pairwise comparisons (with Bonferroni adjustments) of the WBA values across four noise conditions. 1, 2, 3, and 4 indicate quiet, 55 dBA, 65 dBA, and 75 dBA noise conditions, respectively

Frequency [Hz]	Significantly different noise conditions	Difference in mean WBA between quiet and 75 dBA noise conditions	Normalised difference [%]
250	1–2, 1–3, 1–4, 2–4, 3–4	0.011	7.52
315	1–2, 1–4, 3–4	0.010	5.74
400	nil	0.011	4.28
500	nil	0.009	2.84
630	nil	0.014	3.27
800	1–2, 1–3, 1–4, 2–3, 2–4, 3–4	0.033	5.94
1000	1–2, 1–3, 1–4, 2–3, 2–4, 3–4	0.049	7.76
1250	1–2, 1–3, 1–4, 2–3, 2–4, 3–4	0.048	6.93
1600	1–2, 1–3, 1–4, 2–3, 2–4, 3–4	0.033	4.75
2000	1–2, 1–3, 1–4, 2–3, 2–4, 3–4	0.023	3.35
2500	1–2, 1–3, 1–4, 2–3, 2–4, 3–4	0.022	3.17
3150	1–2, 1–3, 1–4, 2–3	0.010	1.44
4000	1–2, 1–3, 1–4, 2–3, 2–4, 3–4	–0.024	–5.02
5000	1–2, 1–3, 1–4, 2–3, 2–4, 3–4	–0.035	–12.94
6300	1–2, 1–3, 1–4, 2–3, 2–4, 3–4	–0.028	–11.25
8000	1–2, 1–3, 1–4, 2–3, 2–4, 3–4	–0.021	–5.74

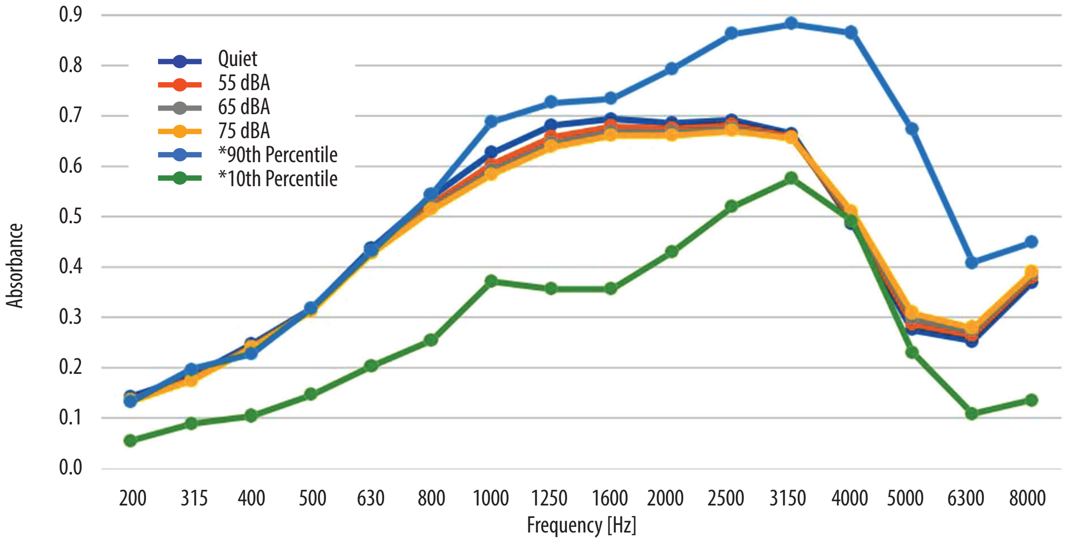

Figure 3. Mean WBA curves for quiet, 55 dBA, 65 dBA, and 75 dBA as determined here (central overlaid lines) lie within the 10th and 90th percentile of normative data (green and blue lines) as determined by Liu et al. [8]

Alternatively, blocks affected by transient noise can also be distinguished from the remaining blocks and discarded.

The spectrum of broadband noise used in the current study might have played a role in the increased WBA levels at high frequencies. The broadband noise spectrum of **Figure 1** suggests that the noise at high frequencies (4000–8000 Hz) is approximately 10 dB higher than at low frequencies. Whether this high-frequency weighting could have contributed to greater noise effects in the WBA measurements requires further investigation.

The sound attenuation capability of the rubber eartips used in the present study is unknown. Vander Werff et al. [19] noted greater differences in test–retest results for rubber tips than for foam tips. However, to date there have been no reference standards for identifying acoustic leaks in WBA testing [20]. Interacoustics (pers comm, 22 October, 2019) additionally noted a lack of published data on the sound attenuation capabilities of the probe tube or eartips. However, they expressed greater concern about physiological noise generated by patients and noise due to probe-tube and shoulder-box movements as being much more influential in measurements. In the present study, great care was taken to instruct the participant to remain still and avoid head or jaw movements during testing.

Although the mean WBA changed significantly with increasing broadband noise levels at all frequencies (except 400–630 Hz), normalised differences in mean WBA between the quiet and 75 dBA conditions were small (≤ 12.9%). This indicates that WBA findings are robust against high levels of broadband noise up to 75 dBA. We observed that mean WBA curves for the four conditions (quiet, 55 dBA, 65 dBA, and 75 dBA) were generally within the 10th–90th percentile of normative data determined by Liu et al. [8] (see **Figure 3**). From a clinical perspective, the changes in WBA due to broadband noise of up to 75 dBA are unlikely to affect clinical decisions except where WBA results are borderline pathological.

Strengths and limitations

The present study is the first to investigate the effects of increasing broadband noise levels on WBA measurements in normal-hearing adults. It provides valuable information on the reliability of the WBA measurements under various background noise conditions (quiet, 55 dBA, 65 dBA, and 75 dBA). In essence, the present study provides evidence that WBA measures are robust against external broadband noise of up to 75 dBA.

Several limitations may have affected our findings. First, it would have been preferable to use flat spectrum noise for the different conditions, rather than the weighted-noise spectrum that was used here. Hence, the present results may not be readily generalised to WBA measurements in other noise environments, such as four-speaker babble noise.

Second, the present study did not compare the effects of different types of probe tips (e.g., rubber versus foam eartips) on the broadband noise received during WBA measurements. Further research is required to identify different types of probe tips and methods that ensure optimal coupling between the probe tip and the ear canal. Such research should also identify whether the specific choice of probe tips leads to greater attenuation of external noise.

Third, the present study employed only one WBA measuring device of one specific make. Presently, various methods exist for measuring WBA and each method has its own inherent variability, which affects the accuracy of the WBA measurement [21]. Given that different WBA measurement systems have different algorithms for noise rejection and signal averaging, our results may not apply to other WBA measuring devices.

Lastly, the present study tested the effect of external broadband noise on WBA only with adult listeners. The results may therefore not be readily generalised to younger populations.

Conclusions

The present study provides evidence that WBA obtained from healthy adults are robust against high levels of external broadband noise of up to 75 dBA. However, the changes in WBA caused by the noise were too small to be of clinical significance. Additional research is needed to extend the findings to pediatric populations.

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