Test Retest Repeatability of Contralateral Inhibition of Transient Evoked Otoacoustic Emissions

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Abstract

The test retest repeatability of transient evoked otoacoustic emission (TEOAE) was assessed for single probe-fit and multiple probe-fit modes in 30 male participants. In single probe-fit mode inhibition of TEOAEs amplitudes were measured twice without altering the position of the probe. In multiple probe-fit mode inhibition magnitudes were measured across different days. The global TEOAE amplitude and amplitude inhibition were measured in both the modes. High reliability was found for TEOAE amplitude for both modes. However, reliability estimates were less for inhibition magnitudes. Inhibition in the single probe-fit mode had higher reliability than the multiple probe-fit mode. Amplitude inhibition had the highest reliability and hence this measure of medial olivocochlear reflex (MOCR) should be considered for all clinical interpretations.

Key words: *Reliability, contralateral inhibition, otoacoustic emissions*

Introduction

The efferent system has two distinct neuronal pathways. Thin and unmyelinated efferent axons originate in the lateral superior olivary complex (LSOC) and synapse with afferent neurons near the cochlear inner hair cells (IHCs). Large and myelinated efferent axons are primarily from the medial olivary cochlear complex and project contralaterally through medial olivocochlear bundle (MOCB) and innervate the outer hair cells (Guinan, 2006). Of the two descending pathways MOCB is most studied due to its accessibility. MOCB can be activated via noise/sound presented to ear or by direct electrical shocks delivered at the floor of the fourth ventricle. Activation of the MOCB results in reduction of the electro-motility of the cochlear outer hair cells and inhibit cochlear responses by reducing the gain from the cochlear amplifier (Guinan, 2006). This reduction of the OHC motility is manifested as reduced basilar membrane displacement, velocity (Russell & Murugasu, 1997), reduction in the magnitudes of otoacoustic emissions (OAEs) (Collet et al., 1994), and compound action potential of the auditory nerve fibers (Liberman, 1989). Functioning of the MOCB can be assessed by monitoring the amplitudes of transient evoked otoacoustic emissions upon the application of the noise in the contralateral ear (Berlin et al., 1993; Collet et al., 1990). Typically, amplitudes of the TEOAEs reduces upon the application of the noise in the contralateral ear and is termed as contralateral inhibition of TEOAEs (Berlin et al., 1993; Collet et al., 1990).

Auditory efferent system is hypothesized to play an important role in protecting cochlea from acoustic injury, speech perception in noise, learning new speech sounds. Therefore, measurement of the contralateral inhibition of TEOAEs may prove to be clinically useful in several applications such as screening individuals for susceptibility to acoustic trauma, as a weakened MOC effect has been observed in laboratory animals that are preferentially susceptible to noise-induced damage (Maison & Liberman, 2000). It can act as an index to monitor efficacy of auditory training (de Boer & Thornton, 2008; Veuillet, Magnan, Ecalle, Thai-Van, & Collet, 2007). Altered MOC inhibitions have been reported in individuals with auditory neuropathy (Starr, Picton, Sininger, Hood, & Berlin, 1996) auditory processing disorders (Muchnika et al., 2004; Sanches & Carvallo, 2006), learning disability (Garinis, Glattke, & Cone-Wesson, 2008), and tinnitus (Ceranic, Prasher, Raglan, & Luxon, 1998). Like- wise, enhanced functioning of the MOC system has been reported in musicians (Perrot & Collet, 2014). Studies have also provided evidence that assessment of the efferent system could be useful in the diagnosis of pontine lesions such as tumors, acoustic neuromas, vestibulocochlear nerve pathology (Prasher, Ryan, & Luxon, 1994; Quaranta, Wagstaff, & Baguley, 2004).

Few studies have assessed reliability of TEOAE inhibition. But, these studies have assessed the reliability of contralateral inhibition of OAEs over one or two recording sessions (Chan & Pherson, 2000; Franklin, McCoy, Martin, & Lonsbury-Martin, 1992; Mishra & Lutman, 2013; Vedantam & Musiek, 1991). However, it is important to evaluate the reliability of TEOAE inhibition over more number of recording settings as the information derived through TEOAE inhibition can be applied to evaluate numerous clinical conditions. The literature suggests that the magnitude of OAE inhibition is very small in quantity that can be affected by a multitude of factors. As the applications of OAEs and its inhibition evolve, there is an augmented need to define and establish the repeatability and reliability of contralateral inhibition of OAEs so as to facilitate its use as a clinical tool in monitoring the auditory function over time.This study aims at studying the test retest repeatability of contralateral inhibition of TEOAEs.

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Objectives of the study

To assess the test-retest reliability of contralateral inhibition of TEOAEs within session and to assess the test-retest reliability of contralateral inhibition of TEOAEs across sessions.

METHODS

Participants

Thirty male participants in the age range of 18 to 25 years (mean age = 21.29 years; SD = 2.19 years) participated in the study. Females were excluded from the study as previous research has shown that oto-acoustic emission (OAE) amplitudes change with the hormonal changes owing to menstrual cycle (Bell, 1992; McFadden, Martin, Stagner, & Maloney, 2009; Yellin & Stillman, 1999). Through a structured interview, it was ascertained that none of the participants had any complaint or history of otological disorders, neurological disorders, noise exposure, ototoxicity or ear infections. Detailed audiological assessment was performed on all participants before recruiting them for the study.

Audiological evaluation consisted of otoscopy, otoacoustic emissions, pure tone audiometry, tympanometry and measurement of ipsilateral and contralateral acoustic reflex thresholds. All these participants had normal hearing sensitivity (less than 15 dB HL) at octave frequencies between 250 Hz and 8000 Hz for air conduction and between 250 Hz and 4000 Hz for bone conduction. Also, all participants had 'A' type tympanogram with static compliance between 0.3 to 1.5cc and peak pressure between +60 and -100 daPa (Margolis & Heller, 1987) and normal ipsilateral as well as contralateral acoustic reflexes at 500, 1000, 2000 and 4000 Hz frequencies. All participants had a mean contralateral acoustic reflex threshold for broad band noise of 70.83 dB HL (SD = 4.37). All participants were right handed on administering the Edinburgh's Handedness Inventory and passed screening test for central auditory processing disorders on the Screening Checklist for Auditory Processing in Adults (SCAP-A) (Vaidyanath & Yathiraj, 2014).

All the tests were conducted in sound treated audiological test rooms (ANSI, 2008). The audiometric and tympanometric evaluations were conducted three times: at the beginning of the experiment, once on the fifth day and at the end of the experiment (15th day).

Stimulus

The Otodynamics ILO v6 system was used to deliver the TEOAE stimulus and record the responses. Clicks of 65 dB peak SPL, at repetition rate 50/s for 260 averages presented in linear mode was used to elicit OAEs. These protocols were selected as previous research has shown that these stimulus parameters are more efficient in eliciting contralateral inhibition (Berlin, Hood, Hurley, Wen, & Kemp, 1995; Goodman, Mertes, Lewis, & Weissbeck, 2013; Guinan, 2006; Hood, Berlin, Hurley, Cecola, & Bell, 1996; Kumar, Hegde, & Mayaleela, 2010; Kumar, Methi, & Avinash, 2013; Kumar & Vanaja, 2004). The broadband noise presented at 60 dB SPL to the contralateral ear served as inhibitor. Suppressor stimuli that are of the same intensity or 5dB greater than the TEOAE eliciting stimuli are effective in maximizing the suppression effect (Berlin et al., 1993).

Procedure

Contralateral inhibition of TEOAE

Participants were made to sit in a comfortable chair and the OAE probe was placed in the test ear and ER 3A insert earphones connected to the audiometer was placed in the contralateral ear. A good seal was ensured and the emissions were recorded with and without noise in the contralateral ear. Participants were instructed not to swallow or make any kind of movement during the testing. The 'auto-adjust stimulus' option was selected before each recording to ensure that the stimulus intensity did not vary more than 2dB from the set criteria.

Each session consisted of three recordings: the first and the third recordings were without contralateral acoustic stimulation (CAS) and the second recording was with CAS. After the first session, participants were given a break of 5-10 minutes and a second session of the same three series of recordings was done. During the break, position of the probe in the test ear was unaltered. This yielded the single probe-fit mode. Following this, experiment (two sessions per day i.e., each session consisting of two TEOAE recording without CAS and one TEOAE recording with CAS recording) was repeated on the next four consecutive days. A gap of 5 to 6 days (average gap = 5.29 days) was provided after the first set of measurements and same protocol was repeated from day 11 to 15. These experiments yielded the values for multiple probe-fit mode. Entire series of experiments was completed within 15 days from its commencement. Figure 3.1 depicts the block diagram of experimental protocol.

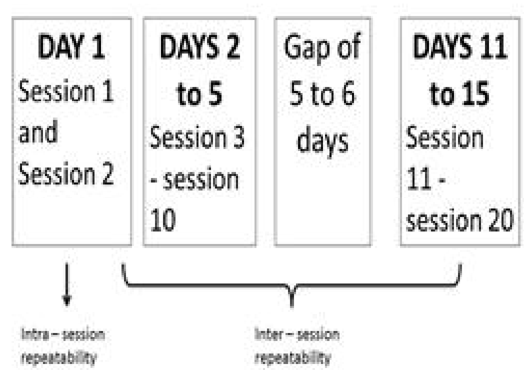

Figure 3.1: Block diagram of experimental protocol

Analyses

The noise (dB SPL), SNR (dB) and the response amplitude (dB SPL) at frequencies 1000, 1500, 2000, 3000 and 4000Hz with and without contralateral noise for the frequencies were noted. Also, the total OAE response amplitude (dB SPL) and total noise (dB SPL) were noted. The difference between TEOAE magnitudes with and without contralateral noise was considered as the magnitude of inhibition. The data was analyzed separately for the intra and inter session recordings.

The following statistical analyses were considered:

1. Repeated measures of ANOVA: to analyze the magnitude of contralateral inhibition.

2. Reliability coefficients Cronbach's alpha and interclass correlation coefficients (ICC): to assess the test/retest reliabilities of contralateral inhibition of TEOAEs.

3. Standard error of measurement (SEM): to calculate 95% confidence intervals of TEOAE inhibition magnitudes. It was calculated using the following equation:

SEM = SD x “π”(1-q)

Where SD is the standard deviation of the set of the observed values, q is the reliability coefficient. SEM was used to calculate 95% confidence intervals of TEOAE inhibition magnitudes.

4. Smallest detectable difference (SDD): The smallest detectable difference is the minimum difference in the inhibition magnitudes that can be considered as real (due to any experimental manipulations), and not due to measurement error or random variations. It was calculated using the formula:

SDD = 1.96 x SEM x “π”2

RESULTS

Primary aim of the study was to evaluate the test retest repeatability of the contralateral inhibition of otoacoustic emissions (OAEs). For this purpose, transient evoked otoacoustic emissions (TEOAEs) were measured with and without contralateral acoustic stimuli (CAS) in multiple sessions. Before analyzing the data, 2 participants who were identified as outliers in the box plots in SPSS were removed and all analyses was performed only on 28 participants. Normality of the data was assessed via Shapiro-Wilk test. As data was normally distributed, parametric statistics were used.

Audiological findings

Pure tone hearing thresholds and immittance evaluations were repeated thrice (1st day, 5th day and 15th day of recording) during the experiment to check the hearing and middle ear status. A repeated measures analysis of variance showed that there was no significant main effect of evaluations (1st, 2nd and 3rd) on pure tone average [$F(2, 54) = 1.23$, $p > 0.05$], tympanometric peak pressure [$F(2, 54) = 0.59$, $p > 0.05$] and static compliance [$F(2, 54) = 1.80$, $p > 0.05$]. These results indicate that hearing thresholds and middle ear status of the participants did not change significantly during the course of the experiment which otherwise would have influenced amplitudes of OAEs.

TEOAE Amplitude

Single Probe-fit mode

TEOAE global amplitudes were noted for all the participants. Figure 4.1 represents the global TEOAE amplitudes obtained (without CAS condition) in single-probe-fit condition across all participants. Figure 4.2 represents the mean and one standard deviation of global TEOAE amplitudes for single probe-fit condition. From the Figures 4.1 and 4.2 it can be seen that TEOAE amplitude did not change much between two recordings in most of the participants. Maximum change observed between two recordings was 3 dB in participant 7. In about 82% of the participants change was less than 1 dB between two recording sessions. Paired t test was done to assess the significance of difference in TEOAE amplitude between two recording sessions. Results revealed no significant difference between the global TEOAE amplitudes between two recording conditions [$t(27) = -0.70$, $p > 0.05$]. To check the reliability Cronbach's alpha and interclass correlation (ICC) coefficients were calculated for single probe-fit mode. Both Cronbach's alpha (0.99) and ICC (0.99) revealed very high reliability for single probe-fit condition.

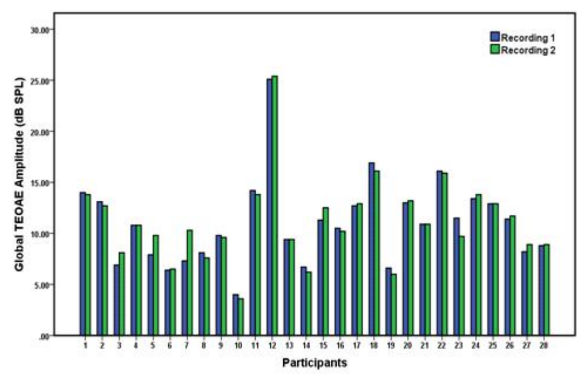

Figure 4.1: Global TEOAE amplitudes for the single probe-fit mode in dB SPL across all participants (recording 1 and 2).

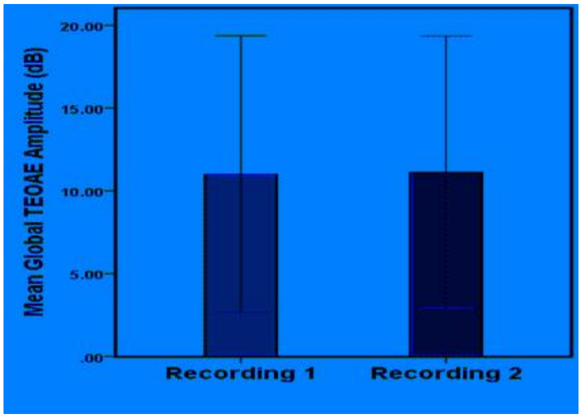

Figure 4.2: Mean and standard deviations of global TEOAE amplitudes for single probe-fit (recording 1 and 2). Error bars indicate one standard deviation.

Multiple Probe-fit mode

Figure 4.3 represents the global TEOAE amplitudes obtained in multiple probe-fit condition. Figure 4.4 shows mean and one standard deviation of TEOAE amplitudes obtained in multiple probe-fit condition. From the Figures 4.3 and 4.4 it can be seen that TEOAE amplitude did not vary much across different recording conditions. In 39% of participants variation in amplitude was less than 3 dB, in 39% of participants variation was less than 5dB across recording conditions. Maximum variation was 9.5 dB for participant 17. A repeated measures ANOVA was performed to assess the significance of differences in TEOAE amplitudes across recording conditions.

Results showed no significant main effect of recording conditions on global TEOAE amplitude [F(5,136) = 0.563, p> 0.05]. Reliability measures are depicted in Table 4.1. From the Table 4.1 it can be inferred that TEAOE amplitudes are highly reliable across different recording sessions.

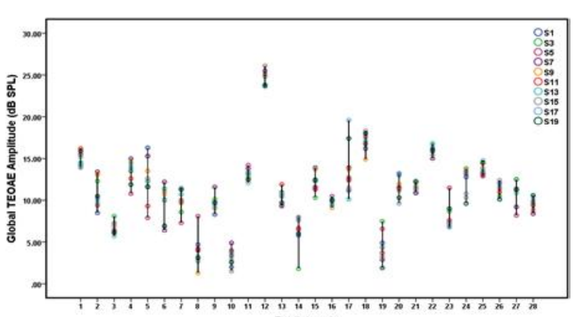

Figure 4.3: Global TEOAE amplitudes for multiple probe-fit mode across all participants.

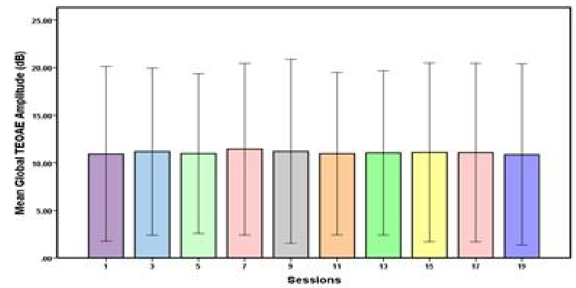

Figure 4.4: Mean and standard deviations of Global TEOAE amplitudes for multiple probe-fit mode. Error bars indicate one standard deviation

TABLE 4.1
Reliability measures for global values in multiple probe-fit mode

Cronbach's alpha	0.99
Single measure ICC	0.91
SEM	0.39
SDD	1.08

TEOAE Amplitude Inhibition

Single probe-fit mode

Contralateral inhibition magnitude was calculated as difference between TEOAE amplitudes without CAS condition (average of two recordings) and TEOAE amplitudes with CAS condition. Figure 4.5 represents the global amplitude inhibition values across all participants for the single probe-fit mode. Figure 4.6 depicts the mean and one standard deviation of global TEOAE amplitude inhibition in single probe-fit mode. From the Figure 4.5 and 4.6 it can be seen that the inhibition values varied across the individuals and also between the recording sessions. CAS typically reduced amplitudes in majority of the participants. However, in a few participants (7, 10, 25 and 27) CAS enhanced TEAOE amplitudes. Maximum variation in inhibition was 1.15 dB for participant 17. The paired-t test revealed no significant difference between the global TEOAE inhibition between two recordings [t(27) = 0.51, p> 0.05]. To check the reliability Cronbach's alpha and interclass correlation (ICC) coefficients were calculated for single probe-fit mode. Both Cronbach's alpha (0.89) and ICC (0.82) revealed moderate reliability for single probe-fit condition.

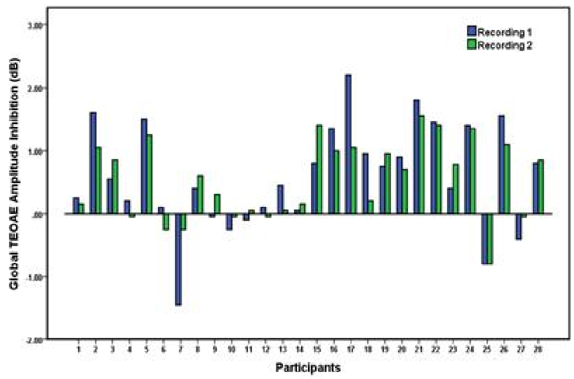

Figure 4.5: Global TEOAE amplitude inhibition for the single probe-fit mode across all participants (recording 1 and 2).

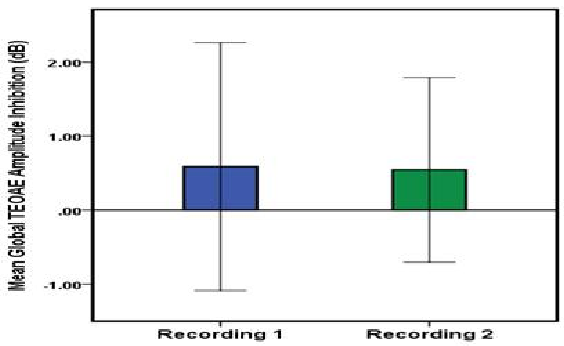

Figure 4.6: Mean and standard deviations of global TEOAE amplitude inhibition for single probe-fit (recording 1 and 2). Error bars indicate one standard deviation.

Multiple probe-fit mode

Figure 4.7 represents the global TEOAE amplitude inhibition values in multiple probe-fit mode across all participants. Figure 4.8 represents the mean global amplitude inhibition values for multiple probe-fit recordings. From the Figures 4.7 and 4.8 it can be seen that the TEOAE inhibition varied across different recording conditions. In 82% of participants variation in amplitude was less than 3 dB, in 18% of participants variation was less than 5 dB across recording conditions. The maximum variation seen was 4.6 dB for participant 17. A repeated measures ANOVA was performed to assess the significance of differences in TEOAE amplitude inhibitions across recording conditions. Results showed no significant main effect of recording conditions on global TEOAE amplitude inhibition [$F(5,161) = 1.42$, $p > 0.05$]. Reliability measures are depicted in Table 4.2. From the Table 4.2 it can be inferred that TEAOE amplitude inhibition are poor to moderately reliable across different recording sessions.

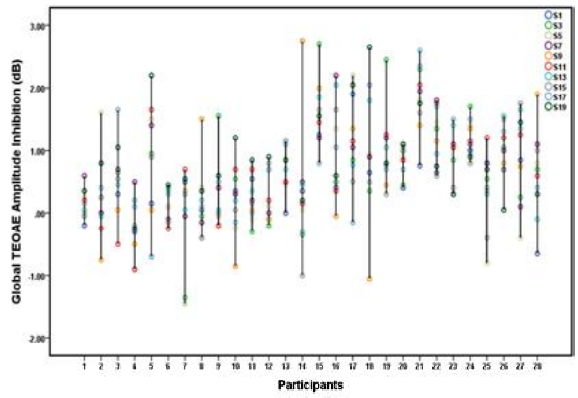

Figure 4.7: Global TEOAE amplitude inhibition for multiple probe-fit mode across all participants.

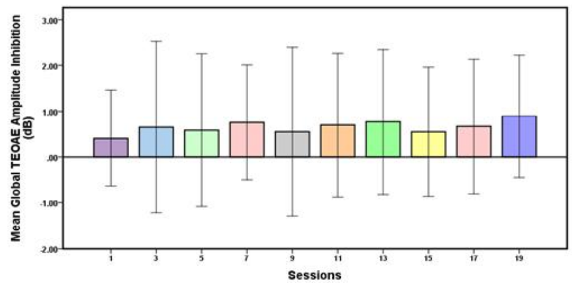

Figure 4.8: Mean and standard deviations of global TEOAE amplitude inhibitions for the multiple probe-fit mode. Error bars indicate one standard deviation.

TABLE 4.2 : Reliability measures for global values in multiple probe-fit mode

Cronbach's alpha	0.86
Single measure ICC	0.37
SEM	0.27
SDD	0.75

DISCUSSION

The test retest repeatability of contralateral inhibition of transient evoked otoacoustic emissions (TEOAE) was studied in 30 male participants. The global TEOAE amplitude and amplitude inhibition were checked in both single probe-fit mode and multiple probe-fit modes.

TEOAE Amplitude

The results for the single probe-fit mode revealed high reliability of TEOAE amplitudes between two recordings. In majority of the participants variation was less than 1 dB. In the multiple probe-fit mode the TEOAE amplitude was slightly more variable than single probe-fit condition. These findings are in accordance with previous research (Franklin et al., 1992; Hurley & Musiek, 1994; Keppler et al., 2010; Marshall & Heller, 1996; Vedantam & Musiek, 1991). Marshall et al (1996) studied the reliability of TEOAEs in 25 normal ears for 10 sessions. They found the intra session amplitude correlation to be as much as 0.86. Franklin et al (1992) assessed the test retest reliability of TEOAEs in 12 participants (7 males and 5 females). TEOAEs were recorded on four consecutive days and they report a reproducibility index as high as 0.9. In another study, Vedantam et al (1991) checked the reliability of TEOAEs on 100 normal ears. The retest was done however on 30 ears and 1.5 hours post initial test. They report a Spearman's correlation coefficient of 0.991.

The slightly less reliability could be due to certain calibration issues inherent to current OAE technology. Despite the auto calibration of the probe before every recording, the intensity level of the stimulus might have varied slightly across the recordings. This is probably due to the presence of evanescent waves at the probe. Evanescent waves are those waves that do not reach termination (Souza, Dhar, & Neely, 2014). The variations in the stimulus delivered and the response spectrum elicited might have led to the variations in the amplitude recorded and resulting reduced reliability in multiple probe-fit conditions.

TEOAE Inhibition

Mean amplitude of inhibition observed in current investigation was 0.56 dB. Even in single probe-fit mode more than 60 % of the participants had inhibition changes more than this value. Though the reliability of the inhibition was high on group data (Cronbach's alpha = 0.89, ICC = 0.82), inspection of the individual inhibition magnitudes showed high variability in few subjects. In few participants, the inhibition varied as much as 1.15 dB (participant 17) even in single probe-fit mode. In the multiple probe-fit mode the reliability was poor to moderate (Cronbach's alpha = 0.86, ICC = 0.37) as a group. On visual examination of individual data, inhibition magnitudes showed high variability in majority of the participants across recording sessions. The maximum variation seen was 4.6 dB for participant 17. Variations in the inhibition magnitudes increased when SNR or normalized amplitudes were considered to calculate the magnitude of inhibition. Our results are not consistent with some of the previous investigation (Graham & Hazell, 1994; Mertes, 2014; Mishra & Lutman, 2013; Stuart & Cobb, 2015). Graham and Hazell (1994) found that across all measurements, mean TEOAE shifts in inhibition ranged from approximately 0.3 - 0.6 dB and the standard deviations ranged from 0.10 - 0.25 dB, indicating small but repeatable effects over time. Mishra and Lutman (2013) reported that when MOCR effects were expressed as the dB change in TEOAE amplitudes, Bland-Altman plots showed that effects changed by 0.03 - 0.07 dB across session for each stimulus level. Cronbach's alpha was 0.8 for four stimulus levels and 0.7 for one level. Mishra and Abdala (2015) also found good long term repeatability of contralateral suppression of distortion product otoacoustic emissions. Stuart and Cobb (2015) report a Cronbach's alpha greater than 0.9 and normalized percentage of TEOAE suppression from absolute amplitude ranging from -1.5% to 1.1%. These findings are in contradiction to that reported by Mishra and Lutman (2013). They found a higher reliability for normalized inhibition compared to the amplitude inhibition.

Reasons for differences between our study and previous research are not clear to us. Some of the possible reasons may be methodology and procedural differences across the studies. For example, Graham and Hazell (1994),was conducted only on 6 participants with wide age range. Similarly, Stuart and Cobb (2015) measured only short term reliability. Moreover all studies mentioned above have looked at reliability measures on group data. Our analyses of group data showed reliability of inhibition magnitudes were moderate to good. But inspection of individual data indicated that variations observed were substantial.

Our results are more consistent with (Kumar et al., 2013; Mishra & Abdala, 2015). Kumar et al, (2013) for DPOAE inhibition magnitudes found that within a single session without probe re-insertion, Cronbach's alpha values ranged from 0.2 to 0.7 and ICC values ranged from 0.1 to 0.6. SEMs, which were calculated using Cronbach's alpha and the standard deviation, were 1 dB or less. SDD values ranged from 1.7 to 2.7 dB. Across multiple sessions Cronbach's alpha ranged from 0.5 to 0.8 and ICC was between 0.1 and 0.3. SEMs were slightly larger (1.6 dB or less), and SDDs also increased (ranged from 1.6 to 4.3 dB). They concluded that variation in the inhibition magnitudes was large and DPOAE inhibition should not be used for clinical purpose.

In the present study care was taken to eliminate other extraneous variables. Females were excluded from the study and the middle ear status of all the participants were monitored throughout. One of the factors that might have contributed to the observed large variations in the magnitude of DPOAE inhibition is attentional states of the participants which were not controlled. Maison et al, (2001) reported that selective attention to an auditory task significantly enhanced the inhibition magnitudes of transient-evoked OAEs. Khalfa et al, (2001) reported the altered MOC activity in individuals whose Heschl's gyrus, amygdale, and hippocampus was surgically removed. These results indicate the role of higher cortical centres in the inhibition of otoacoustic emissions.

CONCLUSIONS

The results of the present study revealed high reliability of TEOAE amplitude and lesser reliability of TEOAE inhibition. The high variability in contralateral inhibition of SNR compared to that of amplitude highlights the importance of utilizing the amplitude measures for clinical purposes rather than SNR measures.

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