# Reliability of Absolute Suppression Amplitude of Transient Evoked Otoacoustic Emissions for Global and Half-Octave Frequency Bands in Children and Adults

# Fiabilité de la valeur absolue de l’amplitude de l’inhibition des otoémissions acoustiques provoquées transitoires dans toute la gamme de fréquences et dans des bandes de fréquences d’une demi-octave chez les enfants et les adultes

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**KEYWORDS**

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CONTINUOUS NOISE

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CHILDREN

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## Abstract

The study aimed to investigate whether the reliability of absolute suppression amplitude of transient evoked otoacoustic emissions was similar for half-octave frequency bands and global values in children and adults. This study is a sequel to Swamy and Yathiraj's (2019) investigation, exploring short-term reliability evaluated at two time points (~4 hours apart) in 15 children and 15 adults. Transient evoked otoacoustic emissions without and with contralateral acoustic stimulus were measured using three methods. In Methods I and II, interleaved white noise having durations of 2 s on-off and 10 s on-off were used respectively; in Method III, continuous white noise was used as the contralateral acoustic stimulus. A significant main effect of methods was observed for absolute suppression amplitude. Method III had the highest absolute suppression amplitude, followed by Method II and Method I. There was no main effect of recordings and age. Reliability was higher for Method III than Methods I and II on three statistical measures (i.e., Cronbach’s α, standard error of measurement, and Bland-Altman plots). Reliability was higher for global absolute suppression amplitude in all three methods compared to the half-octave frequency bands. For the half-octave frequency bands, reliability varied from poor to good for Methods I and II, and good to excellent for Method III. Further, a greater number of participants achieved the smallest detectable difference amplitude in Method III in both age groups. Based on the findings, Method III (continuous contralateral acoustic stimulus) is recommended to measure contralateral suppression of transient evoked otoacoustic emissions in clinical set-ups.

## Abrégé

L'objectif de la présente étude était d'investiguer si la fiabilité de la valeur absolue de l'amplitude de l'inhibition des otoémissions acoustiques provoquées transitoires dans toute la gamme de fréquences et dans cinq bandes d'une demi-octave était semblable chez les enfants et les adultes. Cette étude était la continuité de l'étude de Swamy et Yathiraj (2019) qui a exploré cette même fiabilité à deux moments rapprochés (~4 h d'intervalle) chez 15 enfants et 15 adultes. Des otoémissions acoustiques provoquées transitoires (provoquées avec et sans stimulation acoustique controlatérale) ont été enregistrées dans trois conditions différentes (I, II et III) et à deux moments différents. Dans les conditions I et II, la stimulation acoustique controlatérale consistait en l'utilisation intermittente de bruits blancs dont les activations/désactivations duraient respectivement 2 s et 10 s. Dans la condition III, la stimulation acoustique controlatérale consistait en l'utilisation continue d'un bruit blanc. Un effet significatif de la condition sur la valeur absolue de l'amplitude de l'inhibition a été observé. La valeur absolue de l'amplitude de l'inhibition la plus élevée a été obtenue dans la condition III, puis dans les conditions II et I. Aucun effet d'âge ou du moment de l'enregistrement n'a été observé. La fiabilité était plus élevée pour la condition III que pour les conditions I et II, et ce, pour les trois mesures statistiques utilisées (c.-à-d. le coefficient alpha de Cronbach, l'erreur-type de mesure et le graphique de Bland-Altman). La fiabilité était également plus élevée pour la valeur absolue de l'amplitude de l'inhibition des otoémissions acoustiques provoquées transitoires dans toute la gamme de fréquences que pour celle des otoémissions acoustiques provoquées transitoires dans les cinq bandes de fréquences d'une demi-octave, et ce, dans les trois conditions. En ce qui concerne les cinq bandes de fréquences d'une demi-octave, la fiabilité variait entre mauvaise et bonne dans les conditions I et II et entre bonne et excellente dans la condition III. De plus, un plus grand nombre de participants des deux groupes d'âge ont atteint la plus petite différence perceptible dans la condition III. Les résultats obtenus indiquent que la condition III (qui utilise une stimulation acoustique controlatérale continue) serait celle à recommander pour mesurer l'inhibition controlatérale des otoémissions acoustiques provoquées transitoires en contexte clinique.

The efferent auditory system that encompasses outer hair cells, lateral olivocochlear, the medial olivocochlear (MOC) system, and middle ear muscle reflex (Guinan, 2006) is known to mediate hearing, especially in the presence of noise (Abdala et al., 2014; Kumar & Vanaja, 2004; Mertes et al., 2018, 2019) and localization (Andéol et al., 2011). It is also known to control the sensitivity (Cooper & Guinan, 2006; Kirk & Smith, 2003; Sridhar et al., 1997) and frequency selectivity of the peripheral auditory system (Abel et al., 2009; Maruthy et al., 2017). As the MOC is found to alter the cochlear mechanism, contralateral suppression of otoacoustic emissions has been utilized as a tool to measure MOC bundle function for clinical and research purposes. This has been studied extensively, both in adults and children with normal hearing and different clinical conditions (de Boer & Thornton, 2008; Graham & Hazell, 1994; Kumar & Vanaja, 2004; Muchnik et al., 2004; Pereira et al., 2012). The lack of suppression of otoacoustic emissions was reported to be an indication of reduced or abnormal MOC function in children with auditory processing disorder (Muchnik et al., 2004; Sanches & Carvallo, 2006; Yalçınkaya et al., 2010). Unlike previous studies, Burguetti and Carvallo (2008), Mattsson et al. (2019), and Smart et al. (2019) reported no such findings in children with auditory processing disorder while measuring contralateral suppression of otoacoustic emissions. Mattsson et al. (2019) reported that the mixed outcome seen across studies could be due to the criteria used to diagnose auditory processing disorder and methodological differences in recording contralateral suppression of transient evoked otoacoustic emissions (TEOAEs).

Most studies that evaluated contralateral suppression of TEOAEs have used continuous white noise as the contralateral acoustic stimulus (CAS) and found it to yield good reliability (de Boer & Thornton, 2008; Mishra & Lutman, 2013; Swamy & Yathiraj, 2019). In contrast, mixed findings are reported regarding the reliability of contralateral suppression of TEOAEs measured using interleaved CAS. Satisfactory to good reliability was noted when a white noise that served as a CAS was interleaved for 1.5 s (Stuart & Cobb, 2015), 2 s (Jedrzejczak et al., 2016; Swamy & Yathiraj, 2019), and 10 s (Mertes & Goodman, 2016; Swamy & Yathiraj, 2019). However, Killan et al. (2017) reported fair to good reliability of contralateral suppression of TEOAEs with an on-off duration of 3 s. The reduced reliability in their study was attributed to several subject-related and methodological factors. Based on the above findings, it can be inferred that to evaluate the effect of stimulus-based variables on contralateral suppression of TEOAEs, measuring short-term reliability would be preferred over long-term reliability. In addition, the reliability of contralateral suppression of TEOAEs also depends on the duration of CAS presented. However, most of the studies utilized only one specific duration of CAS. To check the reliability of different durations of CAS, Swamy and Yathiraj (2019) measured contralateral suppression of TEOAEs using three methods that varied in terms of the duration of CAS used (2 s on-off, 10 s on-off, and continuous presentation of white noise). Global amplitude had good reliability for all three methods. Additionally, they found higher suppression amplitude for continuous CAS, followed by 10 s and 2 s interleaved presentation of CAS.

The reliability of contralateral suppression of TEOAEs has been predominantly extracted for global values (de Boer & Thornton, 2008; Mishra & Lutman, 2013; Stuart & Cobb, 2015; Swamy & Yathiraj, 2019). The study by Jedrzejczak et al. (2016) was one of the few that evaluated half-octave frequency bands using a commercial otoacoustic emissions instrument and observed that the reliability varied depending on the frequency of the band. They reported satisfactory reliability for the frequency bands 1 to 2.8 kHz as well as for global values. However, they observed greater variability at 4 kHz compared to the frequencies below 2.8 kHz. Further, TEOAE suppression amplitude is reported to be higher at frequencies below 2.8 kHz (Collet et al., 1990; Goodman et al., 2013; Jedrzejczak et al., 2016; Killan et al., 2017). This trend was attributed to the organization of the MOC fibers' innervations to the cochlea as the region above 4 kHz is sparsely innervated compared to the region below 4 kHz (Guinan et al., 1984; Lewis & Goodman, 2015; Liberman et al., 1990). It is speculated that this variation in innervation of the MOC fibers at different frequencies might influence contralateral suppression of TEOAEs. Hence, it is important to verify the reliability of half-octave bands' contralateral suppression of TEOAEs.

The available literature on reliability of contralateral suppression of TEOAEs using global and half-octave bands is mainly restricted to adults (i.e., de Boer & Thornton, 2008; Graham & Hazell, 1994; Jedrzejczak et al., 2016; Killan et al., 2017; Mishra & Lutman, 2013; Stuart & Cobb, 2015; Swamy & Yathiraj, 2019) and has not been researched much in children. In a recent investigation, Swamy and Yathiraj (2019) reported high short-term reliability for absolute suppression amplitude (ASA) of global TEOAEs, with Cronbach's alpha values of $> .9$ in both children and adults. This was observed for both interleaved (2 s on-off and 10 s on-off CAS) and continuous CAS recordings. Further, they found no significant difference in global ASA of TEOAEs between children and adults. However, they did not assess ASA for half-octave frequency bands. Hence, the present study aimed to determine the reliability of ASA of TEOAEs in children and adults for global and half-octave frequency bands using three methods: Method I, 2 s on-off noise; Method II, 10 s on-off noise; and Method III, continuous noise.

## Method

The study is a continuation of an earlier one (i.e., Swamy & Yathiraj, 2019) that evaluated only global TEOAE suppression amplitude. In addition to the existing half-octave frequency-band data of 27 participants, we studied three new participants. Using a standard group comparison design, we assessed the reliability of global values as well as half-octave frequency-band values of the ASA of TEOAEs in children and adults. We used a purposive sampling technique to select the participants.

### Participants

Participants included 15 typically developing children aged 7 to 9 years and 15 young adults aged 18 to 24 years. None of the participants had a history or presence of any otological problem or hearing loss. This was confirmed because an otoscopic examination indicated no wax or foreign bodies and they had pure-tone thresholds within 15 dB HL. The participants also had A-type tympanogram (**Table 1**) bilaterally, with the static admittance ranging from 0.3 to 0.9 ml in children and 0.3 to 1.7 ml in adults. This suggests normal middle ear function as per the values given by Hanks and Rose (1993) and Roup et al. (1998), respectively. Additionally, the participants had ipsilateral and contralateral acoustic reflex thresholds (0.02 ml threshold criteria) that were ≥ 70 dB HL using a Grason-Stadler GSI TympStar calibrated middle ear analyzer, which ensured that middle ear muscle reflexes did not influence the otoacoustic emissions measurements.

We also ensured that the children and adults were not at risk for an auditory processing disorder from the findings of the Screening Checklist for Auditory Processing (Yathiraj & Mascarenhas, 2004) and Screening Checklist for Auditory Processing in Adults (Vaidyanath & Yathiraj, 2014). This confirmed that they did not have any difficulty hearing in the presence of noise. Further, only participants with TEOAE amplitude ≥ 3 dB above the noise floor for the global response and for three consecutive half-octave frequency bands without CAS were included in the study. Participants included in this study were the same as those in an earlier study (i.e., Swamy & Yathiraj, 2019). One of them did not meet the criteria required for the half-octave frequency

**Table 1**

**Audiological Test Findings Consisted of Pure-Tone Average, Immittance, and Acoustic Reflex Thresholds of Children and Adults**

| Audiological tests | | Children (*n* = 15) | | Adults (*n* = 15) | |
|---|---|---|---|---|---|
| | | *M* (sem) | Range | *M* (sem) | Range |
| Pure-tone average (dB HL) | | 10.33 (0.37) | 7.5 to 12.5 | 10.08 (0.52) | 6.2 to 12.5 |
| Tympanic peak pressure (dapa) | | -13 (3.57) | -40 to 15 | 15 (2.58) | -5 to 30 |
| Static admittance (ml) | | 0.46 (0.04) | 0.3 to 0.9 | 0.63 (0.09) | 0.3 to 1.7 |
| Ear canal volume (ml) | | 0.82 (0.04) | 0.6 to 1.3 | 1.01 (0.05) | 0.8 to 1.3 |
| Ipsilateral acoustic reflex (dB HL) | .5 kHz | 84.33 (0.82) | 80 to 90 | 86.67 (2.05) | 80 to 105 |
| | 1 kHz | 86.33 (1.24) | 80 to 95 | 87.33 (2.17) | 80 to 100 |
| | 2 kHz | 90.33 (1.65) | 80 to 100 | 91.33 (2.15) | 80 to 105 |
| | Click | 89.33 (1.53) | 80 to 100 | 88.00 (2.17) | 75 to 100 |
| | BBN | 78.00 (1.44) | 70 to 85 | 78.67 (2.09) | 70 to 95 |
| Contralateral acoustic reflex (dB HL) | .5 kHz | 91.33 (0.76) | 85 to 95 | 92.67 (2.05) | 85 to 110 |
| | 1 kHz | 92.67 (0.95) | 85 to 100 | 94.00 (2.59) | 80 to 110 |
| | 2 kHz | 95.00 (1.54) | 80 to 100 | 94.67 (2.31) | 80 to 115 |
| | Click | 91.33 (2.03) | 75 to 100 | 88.00 (2.47) | 75 to 105 |
| | BBN | 84.00 (1.30) | 75 to 90 | 81.33 (2.31) | 70 to 105 |

*Note.* sem = standard error of mean; BBN = broad band noise; dB HL = decibels in hearing level; dapa = deca Pascal; ml = milliliter; kHz = kilohertz.

bands, and hence only 27 of those evaluated earlier were included. Among the three newly recruited participants, two were children and one was an adult.

## Procedure

TEOAEs without and with CAS were recorded and analyzed using Echoport ILO 292 otoacoustic emission analyzer with ILO v6 clinical otoacoustic emissions software (Otodynamics, 2011), interfaced with a personal computer. The stimuli consisted of calibrated clicks having a duration of 80-µs, with a peak equivalent level of 60 dB pSPL. The clicks were presented in a linear mode with a repetition rate of 50/s. A total of 260 data samples were recorded, with the noise rejection level set at 6 mPa (49.5 dB SPL). The contralateral suppression of TEOAEs was recorded without and with CAS.

A white noise that served as the CAS was varied in duration to form three methods. Method I had CAS presented for 2 s on and 2 s off at 60 dB SPL. Method II had CAS presented for 10 s on and 10 s off at 60 dB SPL. Method III had CAS presented continuously at 40 dB SL (ref. to pure-tone average of .5, 1, 2, and 4 kHz) from a Madsen OB 922 calibrated audiometer through an Etymotic ER-3A insert earphone. In this method, the noise level in dB SPL varied based on the pure-tone average of the individuals. For individuals with pure-tone average values of 6.25 to 10 dB HL the noise level was maintained at 50 dB SPL. Similarly, for pure-tone average values > 10 to 12.5 dB HL the noise level was maintained at 55 dB SPL. In Method I and Method II, the TEOAEs without and with CAS were recorded with interleaved presentation of white noise through the second probe of the otoacoustic emissions analyzer. The recorded TEOAEs responses were de-interleaved automatically by the analyzer to separate TEOAE without CAS and with CAS at the end of the recording. In contrast, in Method III, 260 sweeps of TEOAEs were recorded without CAS, followed by TEOAEs with CAS, having an inter-recording interval of 120 s between the two recordings. The continuous white noise was presented from an audiometer to enable varying the duration of the CAS for each individual, depending on the number of sweeps accepted (Nlo) and rejected (Nhi). Although the white noise for Method III was generated from an audiometer, unlike that done for Method I and Method II, a spectrum of the two noise sources in the frequency region of interest (1 kHz to 4 kHz) was similar.

The bandwidth of the two noise sources was also similar (see **Figure 1**). These measures were established using a Larsen-Davis 824 sound level meter, with a 1-inch Larsen-Davis 2575 pressure microphone, and 2 cc coupler (AEC203). In all three methods, the recordings of TEOAE without and with CAS were measured only in the right ear of the participants to avoid an ear effect that has been reported in the literature (i.e., Kumar & Vanaja, 2004; Yalçınkaya et al., 2010). The three recordings without CAS served as three baselines.

In both children and adults, recordings were performed twice on the same day, at two different time points, to test the reliability of contralateral suppression of TEOAEs. Prior to each recording, the stimulus level was adjusted using the "Auto-adjust stim" feature available in the instrument. The first recording served as a baseline response. The second recording was performed on all participants 30 minutes to 8 hours (average of ~4 hours) after the baseline recording to check test-retest reliability. The time interval between the two recordings was counterbalanced between the two groups. Thus, for each participant, 12 measurements were obtained at different time points, six without CAS and six with CAS. The first session, which also included the preliminary evaluation, took approximately 90 minutes, while the second session took approximately 40 minutes. During the recording of the TEOAEs, the participants watched a movie they selected with the audio signal muted. This was done to divert their attention away from the click and noise stimuli. This task was incorporated to prevent cortical influence on the medial olivocochlear reflex, as reported in the literature (i.e., de Boer & Thornton, 2007; Kalaiah et al., 2017; D. W. Smith & Keil, 2015; S. B. Smith & Cone, 2015). The study was approved by the All India Institute of Speech and Hearing Ethics Committee (All India Institute of Speech and Hearing, 2009) for bio-behavioural research projects involving human participants. All the audiological assessments were performed in line with the recommendations of the ethical guidelines of the institute (Ref No. Ph.D/AUD-2/2016-2017, dated 18.05.2018).

## Calculation of Contralateral Suppression of TEOAE

To calculate contralateral suppression of TEOAEs, the ASA, standard error of measurement (SEM), and the smallest detectable difference (SDD) were computed in dB SPL, using Equations 1, 2, and 3, respectively, given by Kumar et al. (2013). The SDD was computed to note the minimum acceptable amplitude difference between TEOAEs without and with CAS. This enabled us to determine the ASA that was due to the presentation of CAS and not because of other extraneous or subject related factors.

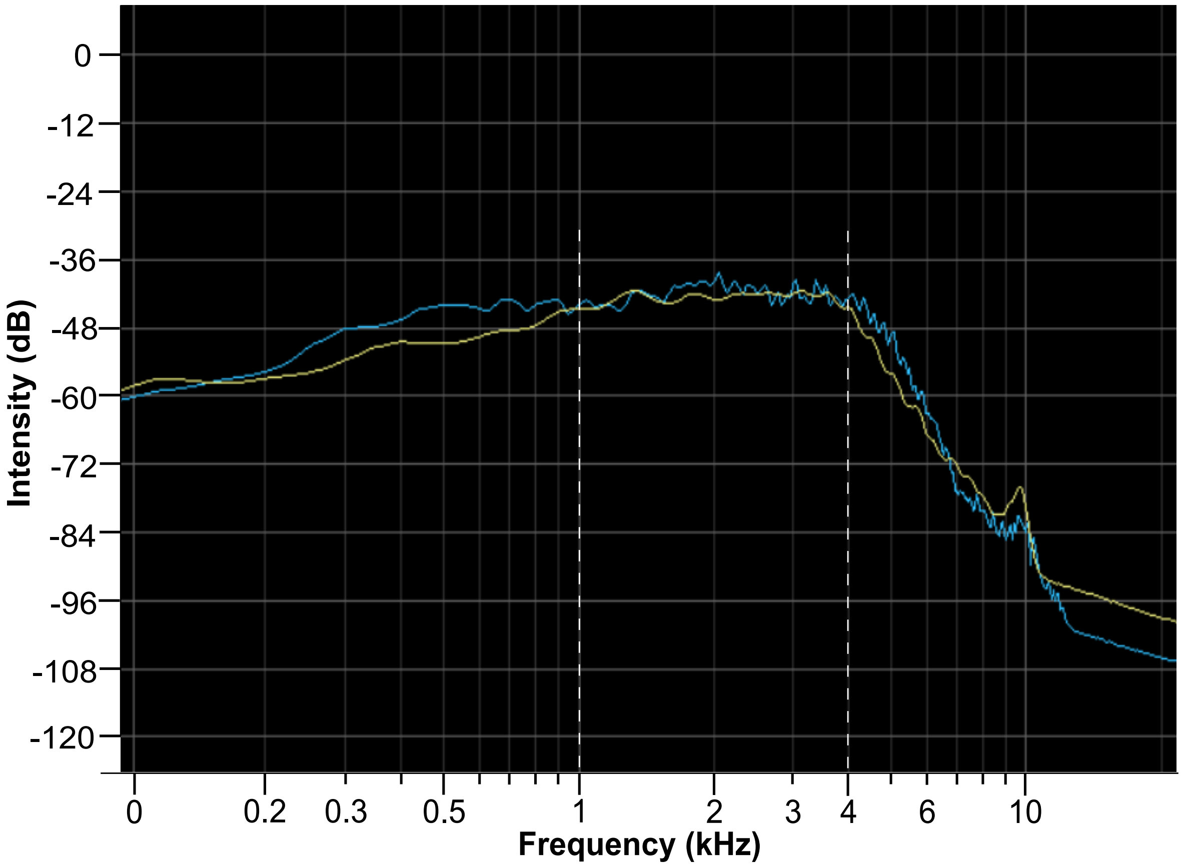
ASA (dB SPL) = TEOAEs without CAS – TEOAEs with CAS ...... *Equation 1*

Where, ASA stands for absolute suppression amplitude and CAS stands for contralateral acoustic stimulus,

$$\text{SEM (dB SPL)} = \sigma(\sqrt{1-\alpha})$$ ...... *Equation 2*

Where, SEM stands for standard error of measurement of

**Figure 1**




White noise spectrum generated from two sources, Madsen OB-922 audiometer represented in yellow line and ILO v6 OAE analyzer represented in blue line. The area between the two vertical dashed white lines represents the frequency region between 1 kHz and 4 kHz.

the ASA; $\sigma$ stands for standard deviation of the ASA; and $\alpha$ stands for coefficient of reliability of the ASA, and

$$\text{SDD (dB SPL)} = 1.96 \times \text{SEM} \times (\sqrt{2}) \qquad \text{...... } \textit{Equation 3}$$

Where, SDD stands for smallest detectable difference of the ASA and SEM stands for standard error of measurement of the ASA.

### Statistical Analyses

Statistical analyses were done using SPSS (version 20) and JASP (version 0.9.1). Because the Shapiro Wilks test indicated that the data were normally distributed, parametric statistics were used. Descriptive and inferential statistics were carried out.

## Results

Prior to analyzing the ASA of TEOAEs, the significance of difference of TEOAE amplitude without and with CAS was calculated using repeated measures analysis of variance (see **Table 2**). The three methods (2 s on-off CAS, 10 s on-off CAS, and continuous CAS) and the two recordings served as within-subject factors and the two age groups served as between-subjects factors. The outcome of the repeated measures analysis of variance of TEOAE varied based on the CAS conditions.

### TEOAE Without and With CAS

The mean TEOAE amplitude without CAS and the amplitude of the noise floor, with one standard error of mean (+/- 1 sem) for the three methods and the two recordings in both children and adults is represented in **Figure 2**. From the figure, it can be seen that TEOAE amplitude varied as a function of frequency bands and participant groups.

**Table 2**

**The Outcome of the Repeated Measures Analysis of Variance of TEOAE Without CAS and TEOAE With CAS for the two Recordings and the Three Methods in Children and Adults**

| Frequency bands | Repeated Measures Analysis of Variance (main effect) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Within subject effects | | | | | | Between subjects effect | | |
| | Methods | | | Recordings | | | Age | | |
| | $F(2, 56)$ | $p$ | $\eta^2_p$ | $F(1, 28)$ | $p$ | $\eta^2_p$ | $F(1, 28)$ | $p$ | $\eta^2_p$ |
| **TEOAE without CAS** | | | | | | | | | |
| Global | 1.41 | .25 | .04 | 6.96 | .01 | .19 | 0.59 | .44 | .02 |
| 1 kHz | 1.15 | .32 | .04 | 7.51 | .01 | .21 | 1.29 | .26 | .04 |
| 1.4 kHz | 1.28 | .28 | .04 | 5.68 | .02 | .16 | 0.38 | .53 | .01 |
| 2 kHz | 1.16 | .32 | .04 | 10.93 | .003 | .28 | 0.06 | .80 | .002 |
| 2.8 kHz | 0.15 | .85 | .005 | 3.22 | .08 | .10 | 1.99 | .16 | .06 |
| 4 kHz | 2.89 | .06 | .09 | 0.12 | .72 | .005 | 2.84 | .10 | .09 |
| **TEOAE with CAS** | | | | | | | | | |
| Global | 81.84 | < .001 | .75 | 6.01 | .02 | .18 | 0.66 | .42 | .02 |
| 1 kHz | 20.91 | < .001 | .43 | 6.60 | .01 | .19 | 2.83 | .10 | .09 |
| 1.4 kHz | 37.07 | < .001 | .57 | 2.45 | .12 | .08 | 1.47 | .23 | .05 |
| 2 kHz | 53.67 | < .001 | .66 | 11.02 | .003 | .29 | 0.03 | .85 | .001 |
| 2.8 kHz | 48.54 | < .001 | .64 | 3.53 | .07 | .11 | 3.20 | .08 | .10 |
| 4 kHz | 39.56 | < .001 | .59 | 0.006 | .93 | .00 | 3.68 | .06 | .12 |

*Note*. TEOAE = transient evoked otoacoustic emissions; CAS = contralateral acoustic stimulus; kHz = kilohertz.

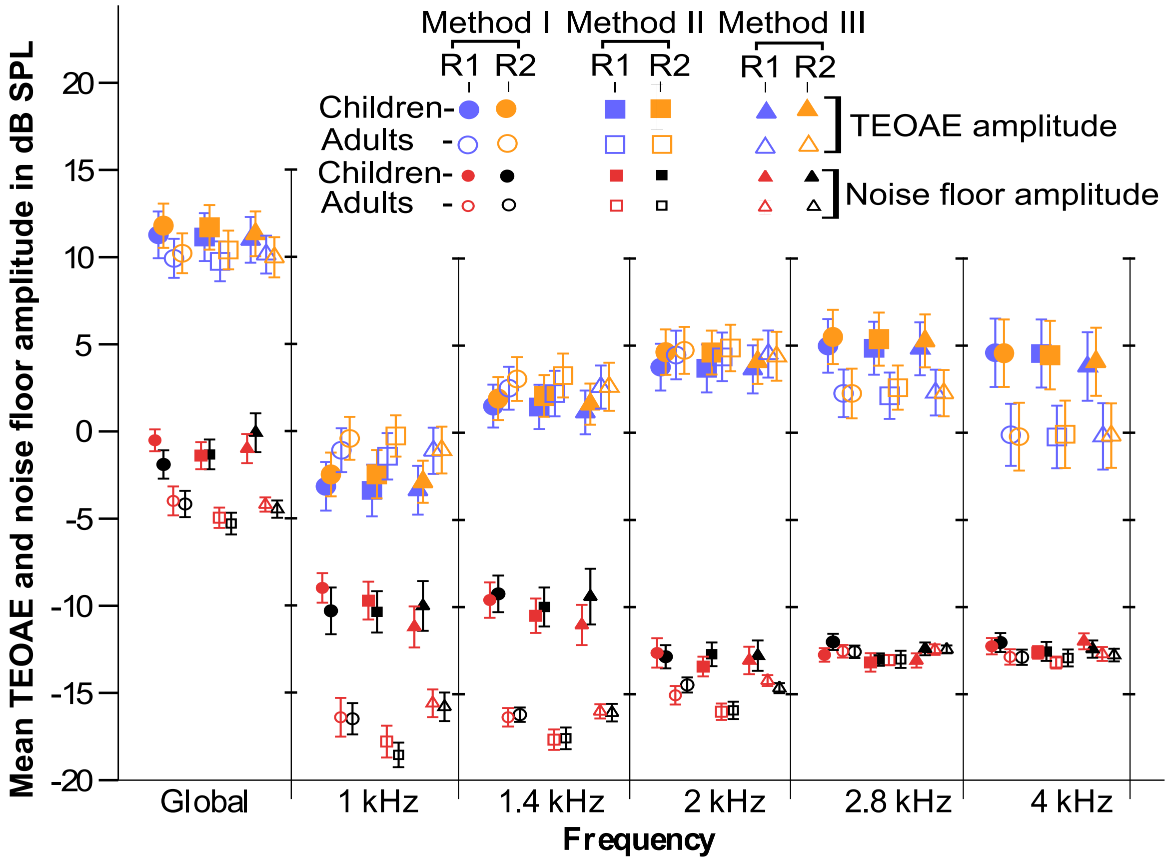
The TEOAE amplitude without CAS had no significant main effect of methods and age for the global as well as the five half-octave frequency bands. However, there was a main effect of recordings for the global and half-octave frequency bands (**Table 2**). An exception was observed for the 2.8 kHz and 4 kHz half-octave frequency bands. A paired *t* test was performed between the two recordings in each of the three methods for global, 1 kHz, 1.4 kHz, and 2 kHz half-octave frequency bands. There was a significant difference between the two recordings ($p < .05$) in Method I and Method II, but not in Method III ($p > .05$). This significant difference was present for the global and three half-octave frequency bands, except at 1 kHz in Method I.

The TEOAE with CAS condition had a significant main effect of methods, but not of age, for both global and five half-octave frequency bands (**Table 2**). Whereas for the recordings, a main effect was present for global as well as 1 kHz and 2 kHz half-octave frequency bands. Post-hoc comparisons with Bonferroni's correction indicated a significant difference between the three methods across global and five half-octave frequency bands. However, there was no significant difference between Method I and Method II at 1.4 kHz and 4 kHz half-octave frequency bands. Comparison between the two recordings in each of the three methods was performed using paired *t* tests for the global, 1 kHz, and 2 kHz half-octave frequency bands. There was a significant difference between the two recordings in Method II for the global, 1 kHz, and 2 kHz half-octave bands ($p < .05$) and in Method I for the global and 2 kHz half-octave band ($p < .05$). However, in Method III there was no significant difference between the two recordings.

### Repeatability of TEOAE Without and With CAS

The reliability between the two recordings for each of the three methods was measured using Cronbach's α. The reliability was high with $\alpha > .9$ for global and five half-octave frequency bands in all the three methods. This was observed for TEOAE without CAS as well as for TEOAE with CAS in both children and adults.

Figure 2




Mean TEOAE and noise floor amplitude with error bars of one standard error of mean (+/- 1 sem) for global and half-octave frequency bands for the two recordings and three methods in children and adults without CAS.

*Note.* Within each frequency band the mean values have been staggered to prevent overlapping of information.

## Absolute Suppression Amplitude

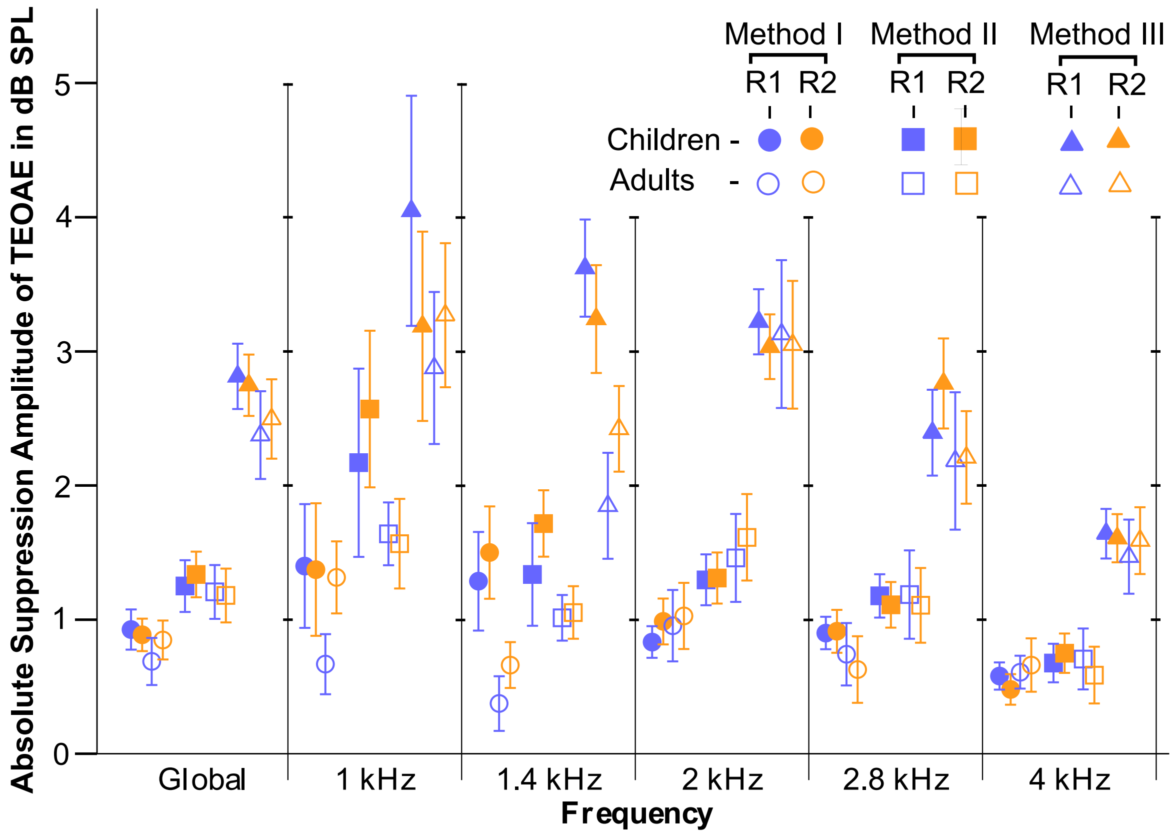
The mean ASA of TEOAEs with error bars of one standard error of mean (+/- 1 sem) for the two groups are represented in **Figure 3**. In general, for the global responses a marginally higher ASA was obtained in children compared to adults in all three methods. Similar results were seen for the half-octave frequency bands, except for 2 kHz where the two groups obtained almost identical suppression amplitude. In both groups, the ASA of TEOAEs was higher for 1 kHz, 1.4 kHz, and 2 kHz half-octave bands, compared to 2.8 kHz and 4 kHz bands, in all three methods. It was also observed that the ASA of TEOAEs was highest with continuous CAS followed by 10 s on-off and 2 s on-off CAS. The ASA values for the two recordings of each participant for the three methods are given in **Figure 4**.

## Difference in Absolute Suppression Amplitude Among Methods, Recordings, and Age Groups

The significance of difference of the ASA across the three methods, two recordings, and two age groups was checked using a 3 (methods) x 2 (recordings) x 2 (age groups) repeated measures analysis of variance. This was done separately for the global values and the five half-octave bands. The methods and recordings served as the within-subject factors and age served as the between-subjects factor.

A significant main effect of methods was obtained for the global, $F(2, 56) = 147.61$, $p < .001$, $\eta_p^2 = .84$, as well as the five half-octave bands: 1 kHz, $F(2, 56) = 16.63$, $p < .001$, $\eta_p^2 = .37$; 1.4 kHz, $F(2, 56) = 52.8$, $p < .001$, $\eta_p^2 = .65$; 2 kHz, $F(2, 56) = 94.1$, $p < .001$, $\eta_p^2 = .77$; 2.8 kHz, $F(2, 56) = 69.69$, $p < .001$,

**Figure 3**



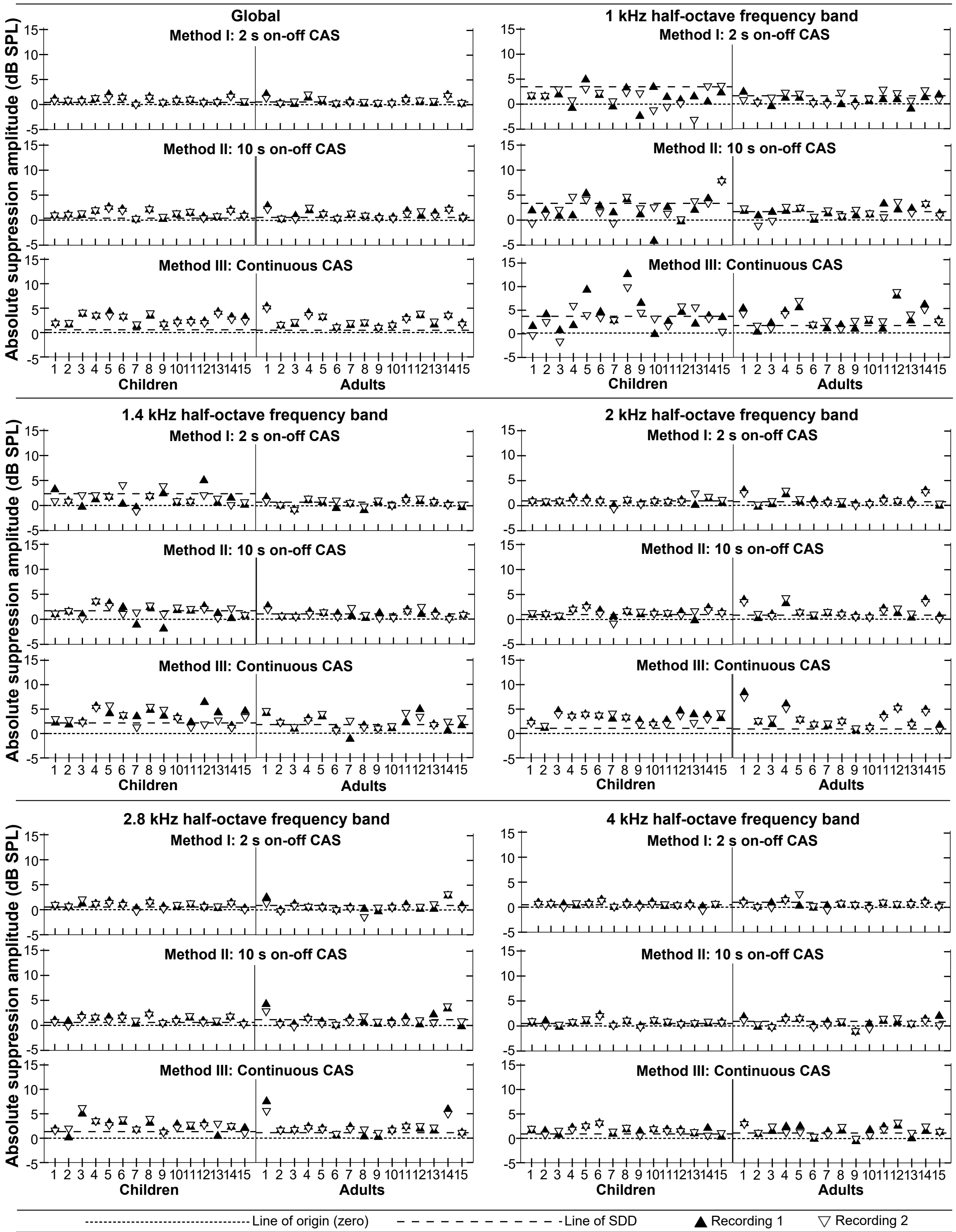

Mean absolute suppression amplitude of TEOAE (dB SPL) with error bars of one standard error of mean (+/- 1 sem) for the two recordings and the three methods in children and adults.

*Note.* Within each frequency band the mean values have been staggered to prevent overlapping of information.

$\eta_p^2$ = .71; and 4 kHz, $F(2, 56) = 58.4$, $p < .001$, $\eta_p^2$ = .67. However, there was no interaction between the methods, recordings, and age of the participants. Pair-wise comparisons with Bonferroni's correction indicated significant difference between the three methods ($p < .001$) for the global values as well as for the half-octave band values. An exception to this finding was seen between methods having CAS durations of 2 s on-off and 10 s on-off at 1.4 kHz ($t = -1.78$, $p = .25$, $d = -0.32$) and 4 kHz ($t = -1.13$, $p = .79$, $d = -0.20$), where no significant difference was obtained.

Unlike what was observed for the main effect of methods, there was no significant main effect of recordings for the global, $F(1, 28) = 1.15$, $p = .29$, $\eta_p^2 = .04$, and the five half-octave band values: 1 kHz, $F(1, 28) = 0.16$, $p = .69$, $\eta_p^2 = .006$; 1.4 kHz, $F(1, 28) = 1.72$, $p = .20$, $\eta_p^2 = .05$; 2 kHz, $F(1, 28) = 0.10$, $p = .74$, $\eta_p^2 = .004$; 2.8 kHz, $F(1, 28) = 0.08$, $p = .77$, $\eta_p^2 = .003$; and 4 kHz, $F(1, 28) = 2.64$, $p = .98$, $\eta_p^2 = .00$. However, a significant main effect of age was seen only for the 1.4 kHz half-octave band, $F(1, 28) = 8.46$, $p = .007$, $\eta_p^2 = .23$, but not for the global value, $F(1, 28) = 1.78$, $p = .46$, $\eta_p^2 = .01$, and other half-octave bands: 1 kHz, $F(1, 28) = 1.25$, $p = .27$, $\eta_p^2 = .04$; 2 kHz, $F(1, 28) = 0.07$, $p = .78$, $\eta_p^2 = .003$; 2.8 kHz, $F(1, 28) = 0.30$, $p = .58$, $\eta_p^2 = .01$; and 4 kHz, $F(1, 28) = 0.003$, $p = .95$, $\eta_p^2 = .00$. Because a significant main effect of age was observed for the 1.4 kHz half-octave frequency band, independent sample *t* tests were done to investigate if the age groups differed from each other significantly, within each of the methods. A significant difference between the two groups was seen for Method I ($t = 2.64$, $p = .013$, $d = 0.96$) and Method III ($t = 2.79$, $p = .009$, $d = 1.02$), but not for Method II ($t = 1.55$, $p = .13$, $d = 0.56$).

## Figure 4




The absolute suppression amplitude of TEOAEs obtained in Recording 1 and Recording 2 of each participant (15 adults and 15 children) for the three methods (2 s on-off CAS, 10 s on-off CAS, and continuous CAS). The data points above the line of identity (zero) indicate the presence of absolute suppression values and the data points below the line of identity indicates absence of suppression.

### Test-Retest Reliability of Absolute Suppression Amplitude

The reliability of the data was determined using Cronbach's α, Bland-Altman plots, as well as SEM. Additionally, SDD was calculated for the two groups and the three methods. SEM and SDD were calculated using equations 2 and 3, mentioned in the Method section.

Internal consistency, measured using Cronbach's α, was found to be excellent for the global amplitude values (α ≥ .9). The α values varied across the half-octave frequency bands, depending on the method and the participant group. These α values were low (< .5) for several of the frequency bands in Method I in children as well as adults, indicating poor internal consistency. In Method II, it was moderate for the lower frequency bands (≤ 2 kHz) and good for the higher frequency bands (> 2 kHz) in the two groups. However, in Method III the α value was good in children for almost all the frequencies. It was excellent in adults for all the half-octave bands, except for the 1.4 kHz and 4 kHz frequency bands where it was good (**Table 3**).

In addition to using Cronbach's α, which provided only the coefficient of reliability and internal consistency, Bland-Altman plots were used to determine the strength (difference plot) and direction (scatter plot) between the two recordings (Bland & Altman, 1986, 1999). The bias values (i.e., the mean of the difference between the two ASAs) for the global and half-octave bands ranged from -.64 to .11 in Method I, -.38 to .12 in Method II, and -.57 to .86 in Method III. This range was seen for both children and adults (**Figure 5** A to F). Because the bias values were close to the line of identity (i.e., zero), it can be inferred that the ASA of the two recordings were identical.

The scatter plots in **Figure 5** (A to F) indicated that the strength of association between the two recordings done at different points of time was positive but varied across the three methods in the two groups. The $R^2$ values were high for the global ASA in all three methods for both children and adults. On the other hand, it ranged from low to high for the half-octave bands. Among the three methods used, the association between the two recordings was highest for Method III but varied between Method I and Method II depending on the frequency of the half-octave bands. The overall reliability in both groups, as observed from the bias values and scatter plots given in **Figure 5**, was generally higher for the global values compared to the half-octave bands.

The SEM also revealed that the reliability of the ASA varied depending on the method, the age group, and whether global or half-octave frequency bands were measured (**Table 4**). The SEM was lowest for the global amplitude in all the three methods in both age groups, indicating that it varied minimally. Likewise, for the half-octave frequency bands, the SEM was relatively lower for the frequency bands above 2 kHz in all the participants. In both groups, the SEM was highest for the 1 kHz half-octave frequency band.

The SDD of the ASA of TEOAEs (**Table 5**) was observed to be lower for the global value compared to the half-octave

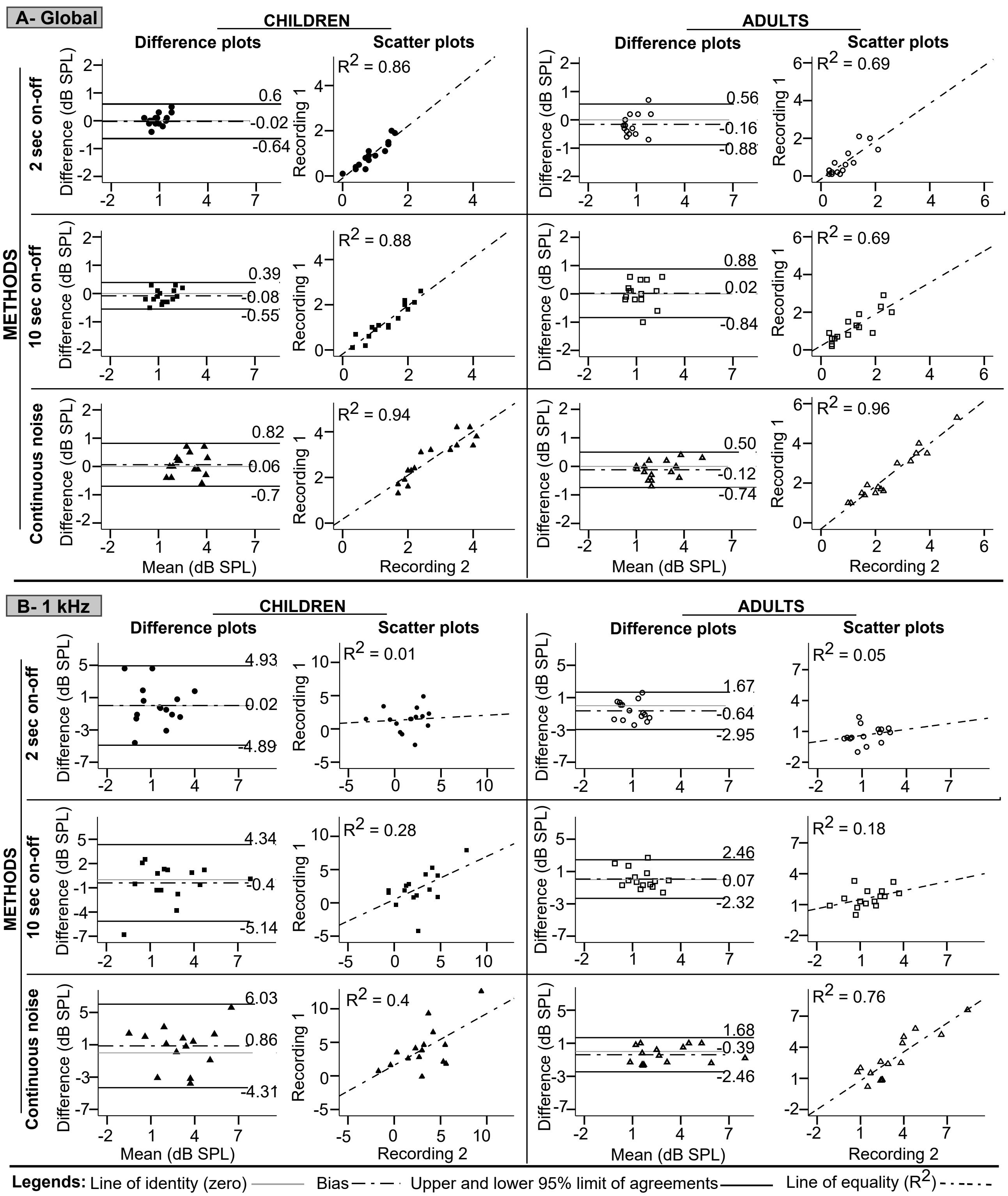
**Table 3**

**Internal Consistency of the Recordings for Global and Half-Octave Frequency Bands in Children and Adults for the Three Methods Using Cronbach's Alpha**

| | Global and half-octave frequency bands | | | | | |
|---|---|---|---|---|---|---|
| | Global | 1 kHz | 1.4 kHz | 2 kHz | 2.8 kHz | 4 kHz |
| **2 s on-off CAS** | | | | | | |
| Children | .91 | .15 | .39 | .38 | .86 | .79 |
| Adults | .89 | .37 | .84 | .92 | .85 | .49 |
| **10 s on-off CAS** | | | | | | |
| Children | .96 | .69 | .67 | .69 | .88 | .89 |
| Adults | .91 | .56 | .61 | .94 | .85 | .81 |
| **Continuous CAS** | | | | | | |
| Children | .95 | .76 | .61 | .81 | .83 | .73 |
| Adults | .98 | .93 | .73 | .97 | .94 | .81 |

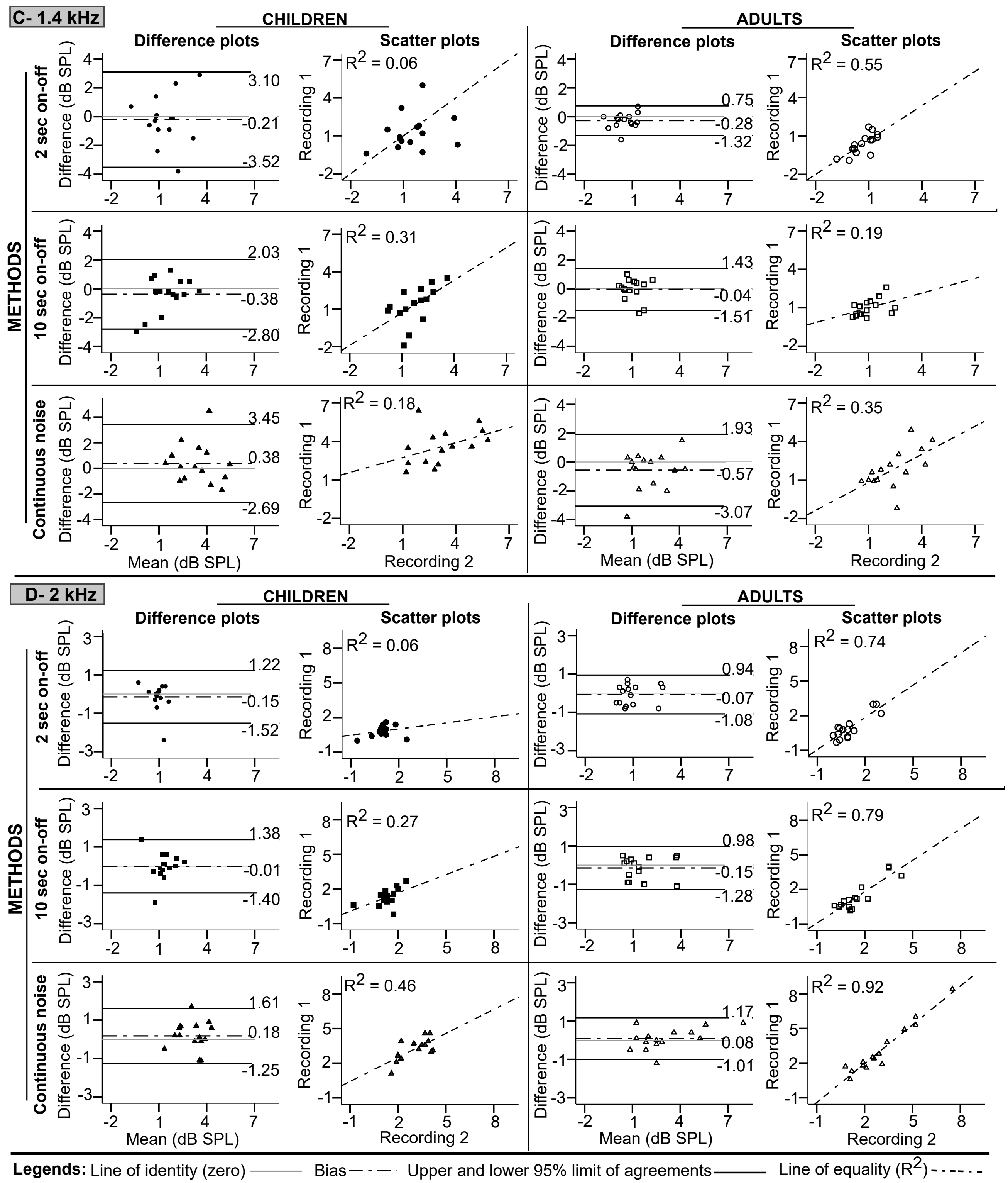
*Note.* α ≥ .9 = Excellent; .9 to .7 = Good; .7 to .5 = Moderate; < .5 = Poor [categorized based on criteria given by Koo and Li (2016), and Tavakol and Dennick (2011)]. CAS = contralateral acoustic stimulus; kHz = kilohertz.

## Figure 5



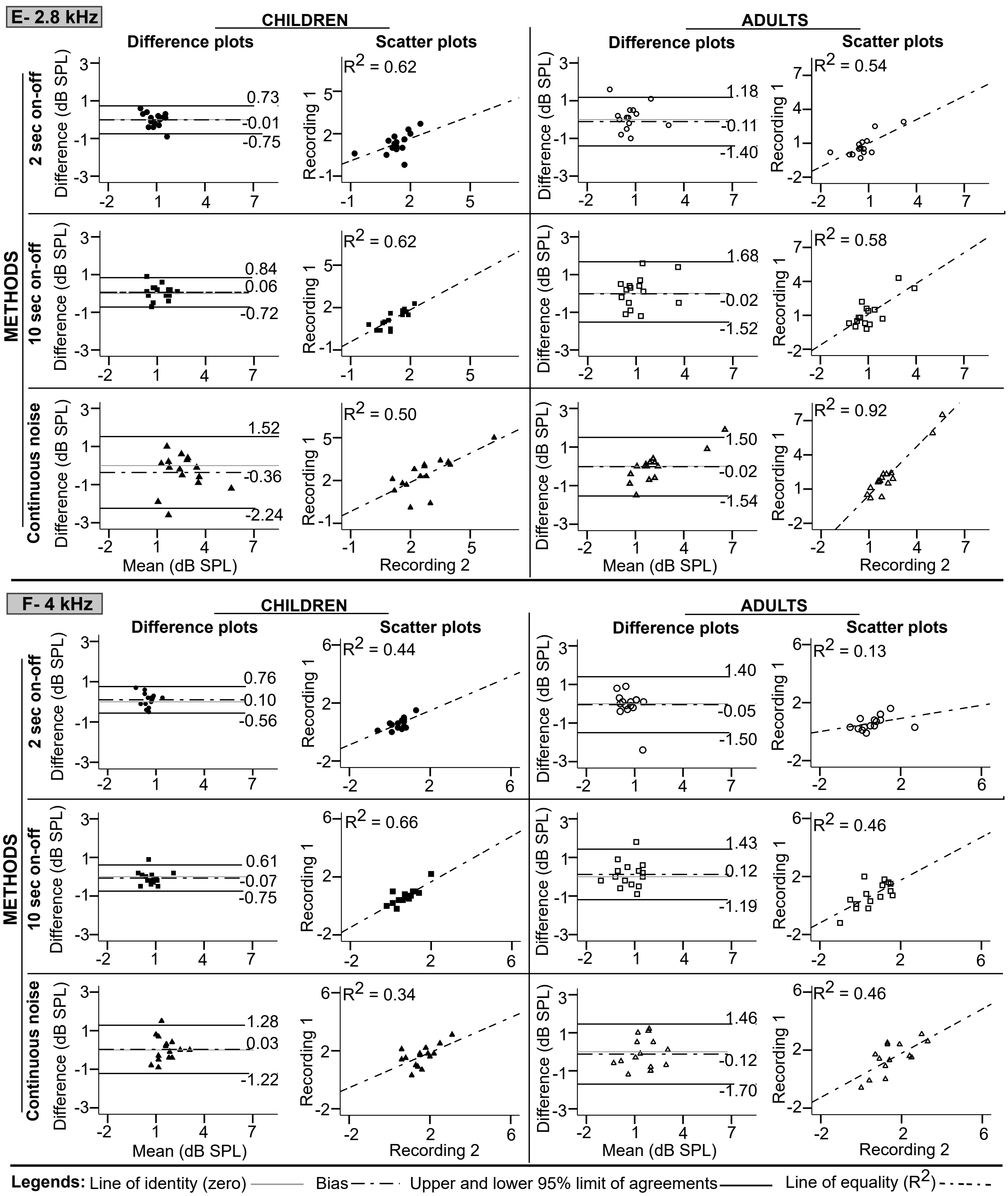

Bland-Altman plots (difference plots and scatter plots) for the absolute suppression amplitude for the global values (A), and half-octave band values [i.e., 1 kHz (B), 1.4 kHz (C), 2 kHz (D), 2.8 kHz (E), and 4 kHz (F)], across three methods (Method I: 2 s on-off CAS; Method II: 10 s on-off CAS; Method III: continuous CAS) in children and adults.

## Figure 5 (Continued)




Bland-Altman plots (difference plots and scatter plots) for the absolute suppression amplitude for the global values (A), and half-octave band values [i.e., 1 kHz (B), 1.4 kHz (C), 2 kHz (D), 2.8 kHz (E), and 4 kHz (F)], across three methods (Method I: 2 s on-off CAS; Method II: 10 s on-off CAS; Method III: continuous CAS) in children and adults.

## Figure 5 (Continued)




Bland-Altman plots (difference plots and scatter plots) for the absolute suppression amplitude for the global values (A), and half-octave band values [i.e., 1 kHz (B), 1.4 kHz (C), 2 kHz (D), 2.8 kHz (E), and 4 kHz (F)], across three methods (Method I: 2 s on-off CAS; Method II: 10 s on-off CAS; Method III: continuous CAS) in children and adults.

**Table 4**

**Standard Error of Measurement of the Absolute Suppression Amplitude for Global and Half-Octave Frequency Bands for the Three Methods in Children and Adults**

| | Global and half-octave frequency bands (dB SPL) | | | | | |
|---|---|---|---|---|---|---|
| | Global | 1 kHz | 1.4 kHz | 2 kHz | 2.8 kHz | 4 kHz |
| **2 s on-off CAS** | | | | | | |
| Children | 0.16 | 1.25 | 0.85 | 0.35 | 0.19 | 0.17 |
| Adults | 0.20 | 0.60 | 0.27 | 0.27 | 0.33 | 0.37 |
| **10 s on-off CAS** | | | | | | |
| Children | 0.14 | 1.21 | 0.62 | 0.36 | 0.21 | 0.18 |
| Adults | 0.22 | 0.62 | 0.37 | 0.30 | 0.43 | 0.34 |
| **Continuous CAS** | | | | | | |
| Children | 0.20 | 1.34 | 0.78 | 0.37 | 0.48 | 0.32 |
| Adults | 0.17 | 0.55 | 0.64 | 0.34 | 0.40 | 0.41 |

*Note.* dB SPL = decibels in sound pressure level; CAS = contralateral acoustic stimulus; kHz = kilohertz.

**Table 5**

**Smallest Detectable Difference of the Absolute Suppression Amplitude for Global and Half-Octave Frequency Bands for Three Methods in Children and Adults**

| | Global and half-octave frequency bands (dB SPL) | | | | | |
|---|---|---|---|---|---|---|
| | Global | 1 kHz | 1.4 kHz | 2 kHz | 2.8 kHz | 4 kHz |
| **2 s on-off CAS** | | | | | | |
| Children | 0.43 | 3.47 | 2.35 | 0.96 | 0.53 | 0.48 |
| Adults | 0.54 | 1.65 | 0.74 | 0.74 | 0.92 | 1.03 |
| **10 s on-off CAS** | | | | | | |
| Children | 0.38 | 3.35 | 1.71 | 0.98 | 0.58 | 0.49 |
| Adults | 0.61 | 1.70 | 1.04 | 0.83 | 1.18 | 0.93 |
| **Continuous CAS** | | | | | | |
| Children | 0.55 | 3.70 | 2.16 | 1.04 | 1.33 | 0.89 |
| Adults | 0.47 | 1.51 | 1.77 | 0.94 | 1.11 | 1.12 |

*Note.* dB SPL = decibels in sound pressure level; CAS = contralateral acoustic stimulus; kHz = kilohertz.

frequency band values. This was seen in each of the three methods for both age groups. Also, for the global values, the SDD varied marginally across the three methods within each age group. The SDD for the half-octave frequency bands tended to be higher for Method III (continuous CAS) compared to the other two methods (2 s on-off CAS and 10 s on-off CAS). Further, the SDD was higher for children compared to adults for the lower three half-octave frequency bands but tended to be higher in adults for the remaining two half-octave frequency bands.

The number of individuals who failed to obtain the required SDD amplitude varied depending on the method used, frequency band that was analyzed, as well as the age group. From **Figure 4** it can be observed that the number of participants who did not obtain the necessary SDD was maximum for Method I, with it varying from two to 11 participants (13% to 73%). For Method II and Method III, the number of participants who did not obtain the SDD amplitude reduced, ranging from one to nine (6% to 60%) and zero to seven (0% to 46%), respectively. Overall, the SDD amplitude was achieved less often for the half-octave bands compared to the global values.

Thus, it can be observed from the study that the ASA of TEOAE was highest for Method III (continuous CAS), followed by Method II (10 s on-off CAS) and Method I (2 s on-off CAS). In all the three methods, a higher test-retest reliability and level of agreement was obtained for the global amplitude compared to the half-octave frequency bands. For the half-octave frequency bands, the method that had the highest reliability varied depending on the frequency of half-octave band, and the age group. Further, a greater number of participants achieved the required SDD amplitude in Method III, in both age groups.

## Discussion

The results are discussed regarding the significance of difference of the ASA of TEOAEs across the three methods, in children and adults. Further, the reliability of the two probe recordings for the three methods that were studied (2 s on-off CAS, 10 s on-off CAS, and continuous CAS) are also discussed. Additionally, the SDD for the different methods are addressed.

The initial analysis of the TEOAEs without CAS indicated that the values did not differ across the three methods that were studied. However, the two recordings measured within Method I as well as Method II were significantly different in both participant groups for most half-octave bands and global amplitude. This difference in recordings was not seen in Method III.

Further, it was observed while recording TEOAEs that more data samples were rejected (Nhi) for Method I and Method II compared to Method III. This could have occurred as the overall duration of the interleaved recordings (~120 s) was almost double that of the measurement with the continuous CAS (~60 s). Due to the longer duration of the interleaved recordings used in Method I and Method II, the participants may have had more difficulty keeping still. Thus, minor head and neck movements due to reflexive swallowing during these recordings may have resulted in an increase in rejection rate. The relatively shorter duration of the continuous CAS recording used in Method III may have enabled the participants to control such movements. This could have led to lesser Nhi for the continuous CAS. It is also speculated that the interleaved recordings could have been influenced by an MOC reflex during the activation and refractory periods.

It has been recommended that recordings should be repeated to confirm that suppression differences seen are due to true change in MOC reflex function and these differences fall within measurement variability (Marshall et al., 2014; Mertes & Goodman, 2016). In the current study, it was observed that a significant difference between the two recordings occurred in Method I and Method II, but not in Method III. Although high Cronbach's $\alpha$ values ($\alpha > .9$) were obtained in all three methods, the absence of a significant difference between recordings in Method III confirms that this method is the choice when evaluating children as well as adults.

### Comparison of Absolute Suppression Amplitude with CAS Across Methods

In the present study, significant difference across methods was observed with the use of CAS. However, no such difference was observed when the measurements were done without CAS. This indicates that it was the type of CAS that influenced the ASA of TEOAEs. Among the three methods, greater ASA of TEOAEs was present in Method III followed by Method II and Method I, in both the age groups for the global and for half-octave frequency bands. This increase in ASA of TEOAEs with increase in the duration of CAS could indicate the time course of the medial olivocochlear reflex, noted earlier in animals (Cooper & Guinan, 2003; Sridhar et al., 1995) as well as in humans (Backus & Guinan, 2006; Bassim et al., 2003; Kim et al., 2001). The lower ASA seen when shorter CAS were used could be a reflection of the activation of the fast and medium phase of the MOC reflex time-course to short CAS, as noted in the literature (Cooper & Guinan, 2003; Sridhar et al., 1995).

Additionally, it is proposed that the slow MOC reflex could have contributed to the difference in suppression amplitude seen with increase in duration of CAS. The sustained duration of CAS up to ~60 s could have led to a change in axial stiffness of the outer hair cells due to the slow MOC reflex. This slow reflex is noted to be a separate MOC reflex mechanism as it results in a change of phase from what is observed for the fast MOC reflex (Cooper & Guinan, 2003). Cooper and Guinan (2003) proposed that the slow reflex of the MOC could result in reduction of cell stiffness. This reduction was found to occur by depolarization of the cells (He & Dallos, 1999). Thus, such depolarization of outer hair cells, consequent to the slow

MOC reflex could have led to increased suppression, especially for the relatively longer CAS in the current study.

Further, the global ASA seen in Method III of the current study, where a continuous CAS was used, was higher than that obtained in earlier studies (i.e., de Boer & Thornton, 2008; Mishra & Lutman, 2013). While the mean absolute suppression was 2.8 dB SPL (range = 1.30 to 4.20 dB) and 2.38 dB SPL (range = 1.0 to 5.30 dB) for children and adults, respectively in the current study, it was reported to be 1.38 dB SPL by de Boer and Thornton (2008) and 1.87 dB SPL by Mishra and Lutman (2013). This higher suppression observed in the present study could be attributed to the responses being measured in the presence of a passive visual task, where the participant's attention was diverted from the auditory stimuli using a video. The video, with the audio muted, was presented during the measurement of TEOAE without and with CAS. It has been reported in the literature that the ASA of TEOAEs increases when the attention of a participant is diverted away from the click and CAS or towards another sensory modality (de Boer & Thornton, 2007; Harkrider & Bowers, 2009; Kalaiah et al., 2017; S. B. Smith & Cone, 2015; Walsh et al., 2015). Thus, it may be inferred that ASA obtained in this study is a true representation of MOC function.

For the half-octave bands, the ASA of TEOAE tended to be greatest for the 1 kHz and least for the 4 kHz band, in all three methods and two age groups (**Figure 3**). Studies in the literature have attributed this variation in ASA of TEOAEs to the action of the MOC. Greater ASA on account of an MOC effect were reported for otoacoustic emissions recorded for 1 kHz to 2 kHz region (Collet et al., 1990; Goodman et al., 2013; Jedrzejczak et al., 2016; Lewis & Goodman, 2015). Further, the reduction in ASA in the present study at 4 kHz could be due to the organization of the efferent innervation to the cochlea. A decrease in efferent innervation has been noted for frequency above 4 kHz (Collet et al., 1990; Goodman et al., 2013; Guinan et al., 1984; Lewis & Goodman, 2015; Liberman et al., 1990), which may have resulted in the reduced ASA at 4 kHz.

In addition to the organization of the efferent innervation, lower suppression at the higher frequencies has been suggested to be on account of a lower signal-to-noise ratio (SNR) at 4 kHz (Goodman et al., 2013; Jedrzejczak et al., 2016). In the present study, this explanation holds well for the adults but not for the children. The former group had SNRs that were lower for 4 kHz (~12 dB SNR) compared to the other half-octave frequency bands (> 15 dB SNR), as noted in literature. On the other hand, in the latter group the SNR was greater at the higher frequencies (2, 2.8, and 4 kHz = ~17 dB SNR) compared to the lower frequencies (1 kHz = ~7 dB SNR; 1.4 kHz = ~12 dB SNR). Hence, it can be construed that the effect of SNR on contralateral suppression of TEOAE amplitude across the half-octave frequency bands cannot explain the variations in the ASA of TEOAE across the frequency bands. Other physiological mechanisms could have played a role in the variations in the ASA across the half-octave frequency bands.

### The Reliability of Absolute Suppression Amplitude

The reliability of measuring global ASA of TEOAE was high in the current study, substantiated through three different statistical procedures (Cronbach's $\alpha$, Bland-Altman plots, and SEM). The internal consistency of the global values was excellent ($\alpha \geq .9$) in all three methods in both participant groups. This is in agreement with the previous studies done on adults where the reliability ranged from good to excellent (Mertes & Goodman, 2016; Mishra & Lutman, 2013; Stuart & Cobb, 2015). Thus, the global values found in the present study in both age groups are in consonance with that observed in studies done on adults. With respect to the half-octave bands, in the present study the reliability varied depending on the frequency as well as the method used. The findings obtained in Method I were in consensus with that of Jedrzejczak et al. (2016), who used 2 s on-off CAS and reported poor to satisfactory reliability across the half-octave bands. However, in the present study this reliability improved with increase in duration of CAS with it being good to excellent for Method III across the half-octave frequency bands. These findings were further substantiated by the high correlation ($R^2$) and SEM values.

Further, the bias value of global in the Bland-Altman plots was similar to that reported by Mishra and Lutman (2013) and Stuart and Cobb (2015). This indicates less variability between the two measures of ASA, in both age groups. However, the 95% limit of agreement differed between the children and adults in the present study. This difference depended on the frequency of the half-octave bands and the methods. Overall, the children had a wider range for 1 kHz, 1.4 kHz, and 2 kHz half-octave frequency bands, while the adults had a narrower range (**Figure 5** A to F). However, for the higher half-octave frequency bands (2.8 kHz and 4 kHz), the adults had a wider range compared to the children, except for the 2.8 kHz half-octave band for Method III. These variations between children and adults could be attributed to differences in their SNR values obtained across the half-octave bands.

Additionally, it was ruled out that the TEOAE amplitudes were not influenced by the middle ear functioning, as the tympanic peak pressure and static admittance (**Table 1**) were within the recommended limits given in the literature (Marshall et al., 1997; Trine et al., 1993; Veuillet et al., 1992). This was also confirmed with low or no significant Pearson product moment correlation between the middle ear measurements and ASA in all three methods. Likewise, the acoustic reflex thresholds were ≥ 70 dB HL (**Table 1**) and hence were unlikely to have influenced the contralateral suppression of TEOAEs as the CAS levels were ≤ 60 dB SPL. It has been reported in the literature that when the CAS levels are below that of the middle ear muscle reflex thresholds, they are unlikely to influence the contralateral suppression of TEOAEs (Buki et al., 2000; De Ceulaer et al., 2001; Hood et al., 1996; Plinkert et al., 1994; Zhao et al., 2000). However, the influence of middle ear muscle reflex below threshold levels on contralateral suppression of TEOAEs are unknown.

The SDD varied across the methods used and between the participant groups (**Figure 4**). As mentioned earlier, most of the participants in both the age groups achieved the target SDD for Method III, while fewer participants did so for Method I and Method II. This indicates that the ASA obtained using the continuous CAS in Method III was influenced to a lesser extent by extraneous or participant-related factors, unlike the other two methods.

Mertes and Goodman (2016) reported that for some participants a change of 1.5 to 2 dB in suppression amplitude was required to quantify it as MOC reflex. However, in the present study the minimum acceptable amplitude obtained was ~0.5 dB for Method III (continuous CAS) in both age groups for the global value. Furthermore, the mean value for Method III was relatively higher than the SDD, implying that the ASA obtained is due to MOC reflex and not any extraneous variables.

It is recommended that the findings of the present study could be used to assist in differentiating normal and deviant MOC functioning by using ASA values to supplement the findings of behavioural tests. It may not be possible to specify a particular cut-off value of ASA to separate normal or abnormal function of MOC, based on the present findings. Nevertheless, drawing support from earlier investigations (De Ceulaer et al., 2001; Muchnik et al., 2004; Prasher et al., 1994), suppression value of greater than or equal to 1 dB may be used to differentiate normal and deviant MOC functioning. Suppression values of < 1 dB could be considered to suggest reduced activity of the MOC bundle. This value is recommended for continuous presentation of CAS at 40 dB SL.

A limitation of the study is that we did not actually measure participants' speech perception in noise and participants only reported no difficulty in hearing in the presence of noise. It is suggested that further research be conducted in individuals with and without poor scores on a speech-in-noise test and correlation of the same with contralateral suppression of TEOAEs may provide further insight on MOC function.

## Conclusions

The amplitude of the TEOAEs without and with CAS, measured using three methods (2 s on-off CAS, 10 s on-off CAS, and continuous CAS) and two recordings on 15 children and 15 adults, varied depending on the CAS conditions. Although no significant difference was observed between the three methods in TEOAE without CAS, there was a significant difference with CAS. Further, no significant difference was obtained between the recordings in Method III unlike Method I and Method II in both CAS conditions.

Method III, which made use of continuous CAS, was found to have the highest ASA, followed by Method II and Method I. This was observed for global as well as half-octave frequency bands. Further, no significant difference was seen between children and adults except at 1.4 kHz in Method I and Method II. The reliability of the ASA of TEOAEs was found to be higher for global values compared to the half-octave frequency bands. Overall, continuous presentation of CAS had excellent to good reliability, as observed from the findings of the different statistical measures that were carried out. Hence, it is recommended to use continuous presentation of CAS (Method III) rather than interleaved CAS while measuring global and half-octave frequency bands for both children and adults. As global responses were found to have high reliability, it is suggested that a single measurement is adequate in clinical practice when using it. The total duration for single measurement for the two ears would require ~10 minutes. However, if half-octave frequency bands are necessary, it is suggested that at least two baseline recordings are used to confirm reliability of the responses. This would require ~20 minutes in total. Thus, with changes in the number of baseline recordings, half-octave frequency bands can also be utilized effectively. Furthermore, inclusion of a passive visual task is likely to result in greater ASAs and result in less cognitive load in children.

We suggest that further research be done using Method III to investigate MOC function in the clinical population such as those with auditory processing disorder and learning disability. As continuous CAS had good reliability in the measurement of contralateral suppression of TEOAE, it could be used in clinical practice.

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