Indonesian Journal on Health Science and Medicine

Vol. 3 No. 1 (2026): July
DOI: 10.21070/ijhsm.v3i1.492

ISSN 3063-8186 (online), https://ijhsm.umsida.ac.id, published by Universitas Muhammadiyah Sidoarjo

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DOI: 10.21070/ijhsm.v3i1.492

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DOI: 10.21070/ijhsm.v3i1.492

Transient Evoked and Distortion Product Otoacoustic Emission Comparison in Children

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Abstract

General Background Otoacoustic emissions objectively evaluate outer hair cell function in pediatric populations. **Specific Background** Transient evoked and distortion product paradigms are widely used to assess cochlear responsiveness in pediatric hearing screening. **Knowledge Gap** Comparative evaluations of signal-to-noise ratio performance across matching frequencies, alongside ear asymmetry and gender dynamics in six-year-olds, remain limited. **Aims** This study compared screening pass rates, signal-to-noise ratios, and ear or gender variations between both emission paradigms in normal-hearing children. **Results** Among 130 children (260 ears), both paradigms showed identical 100% pass rates, though distortion product emissions yielded significantly higher signal-to-noise ratios at 2, 3, and 4 kHz ($p < 0.001$), with mostly nonsignificant ear side and gender variations. **Novelty** This work establishes normative baseline comparative parameters in six-year-olds, proving distortion product signal superiority at identical frequencies. **Implications** Superior distortion product signal strength provides a clinically advantageous paradigm for pediatric auditory assessment, particularly in noisy environments.

Keywords: Transient Evoked Otoacoustic Emissions, Distortion Product Otoacoustic Emissions, Pediatric Hearing Screening, Signal to Noise Ratio, Cochlear Function

Key Findings Highlights

Both emission paradigms achieved equivalent hundred percent screening pass rates among healthy six-year-old pupils.

Signal-to-noise ratios were significantly greater in distortion product measurements across identical testing frequencies.

Gender and ear side variations remained absent across most frequencies, establishing baseline pediatric normative parameters.

Published date: 2026-07-19

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Introduction

Audiology is the discipline involved in the prevention, identification, evaluation of hearing disorders and the rehabilitation of individuals with hearing loss [1] in addition to balance assessment and management. Hearing assessment includes behavioral measures and objectives methods (physiological measures)[1,2], these physiological measures are provide an objective tool for assessing auditory sensitivity at specific levels of auditory pathway thus behavioral methods remain the only functional measures for assessing the complete auditory system[3]. Sometime the behavioral methods have some limitation specially in uncooperative young child, uncooperative adult and nonorganic hearing loss, so we should do the objective methods [2,3,4]. Otoacoustic emissions (OAEs) is a diagnostic method widely used during the past decade to study cochlear function (peripheral auditory system), in a non-invasive and objective manner [4,5,6] .

Otoacoustic emission (OAEs): are low-intensity sounds that are generated by the cochlea and emanate into the middle ear and ear canal. They are frequency specific in that emissions of a given frequency arise from the place on the cochlea's basilar membrane responsible for processing that frequency. OAEs are probably not essential to hearing, but rather are the by-product of active processing by the outer hair cell system (OHCs). Of clinical interest is that OAEs are present when OHCs are healthy and absent when outer hair cells are damaged [1,2,7]. OAEs are a pre-neural phenomenon and can be measured even when the eighth nerve has been severed. In addition, OAEs are vulnerable to acoustic trauma, hypoxia, and ototoxic medications, which cause hearing loss and damage to OHCs, OAEs do not appear to be vulnerable to selective loss of inner hair cells (IHCs). OAEs produced by Somatic motility of OHCs and active hair bundle movement of the hair cell sterocilia, there is two OAEs generation mechanisms nonlinear distortion (wave fixed) and linear reflection (place - fixed)[5,8] .

There are two types of OAEs based on the recording paradigm: Spontaneous Otoacoustic Emissions SOAEs and Evoked Otoacoustic Emissions EOAEs. EOAEs require a stimulus of some sort to produce them, where as SOAEs simply occur spontaneously (without a stimulus), **S**OAEs are narrow-band signals (1-3 KHz), Spontaneous emissions are present in (50 - 70%) of all normal-hearing ears and absent in all ears at frequencies where sensorineural hearing loss (SNHL) exceeds approximately 30 dB HL [2,3,4]. **S**OAEsare not of much clinical value at present.

EOAEs, however, have been demonstrated to be sensitive to damage to the hair cells in the cochlea and have become a key clinical tool for the detection and diagnosis of hearing loss. There are basically three types of EOAEs: Stimulus-Frequency OAE (SFOAE), Transient-Evoke OAE (TEOAE) and Distortion-Product OAE (DPOAE), The SFOAEs are the most difficult to measure and have been studied the least. They are produced by presenting the ear with a pure tone and then examining the sound recorded in the ear canal. The frequency of the emission sound, however, is the same as that of the stimulus tone and its level is much lower than that of the stimulus, this makes it difficult to measure and study.

TEOAEs are recorded by stimulating the ear with a brief click stimulus (80-85 dB SPL) while recording the sound level in the ear canal with a tiny microphone (low noise microphone) [1,2] the responses can be recorded from new born greater than 20 dB SPL while responses from children and adult range between 10 and 15 dB SPL [5,8]. A click is a brief sound that has energy spread over a wide range of frequencies. Thus, a wide range of the basilar membrane can be stimulated in an instant. Because of the nature of the traveling wave mechanism in the cochlea, the basilar membrane initially responds to a click with maximum displacement in the high-frequency basal region then travels toward the apex low-frequency region, it takes longer for the low-frequency sounds to travel to the apex and stimulate the basilar membrane. Further, the vibrations producing the emissions travel back out of the cochlea at the same rate, so that low-frequency sounds would come back out of the cochlea and be measurable by a microphone in the ear canal after the high frequencies appeared [1,9]. TEOAEs occur after 4 msec. following the stimulus presentation and continue for about 10 msec [2,4]. As shown in figure (1):

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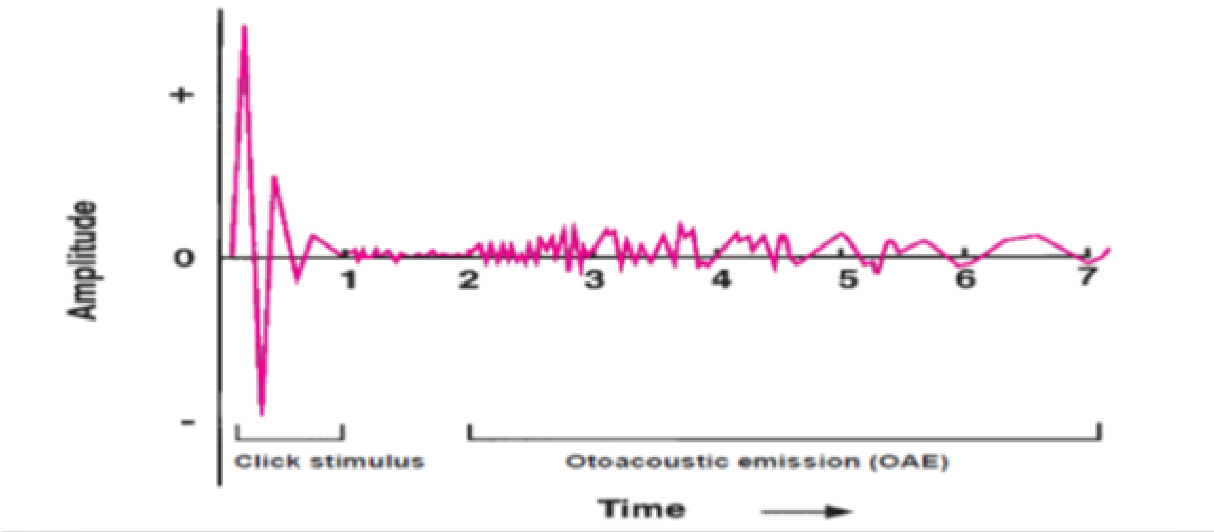

Figure 1.

Figure (1) : TEOAEs in normal hearing individual .

The third type of EOAEs is the DPOAEs, distortion is character of many systems include mechanical system and can measured in variety of ways. One of manifestation of distortion to the system is give sound stimulus to the system this result one emerge output tones that were not part of sound stimulus, these additional tone referred as Distortion Product (DP). When two sound (tones) of long duration are applied to auditory system the most prominent DP are 2F1-F2 (have greater amplitude), this called cubic difference tone (CDT) and the CDT is lower than two applied tones in frequency. the DPOAEs refer to nonlinearity of cochlea, paired of tones primaries (9 paired of primaries) presented typically across frequency range to elicit DP, this paired have fixed intensity and frequency relationship F2\F1 =1.2 for all frequency used to determine the DP frequency and the stimulus intensity F2 55 dB SPL and F1 65 dB SPL . The distance between primaries and the audiological frequency is 1\6 octave [1,2]. As shown in figure (2) :

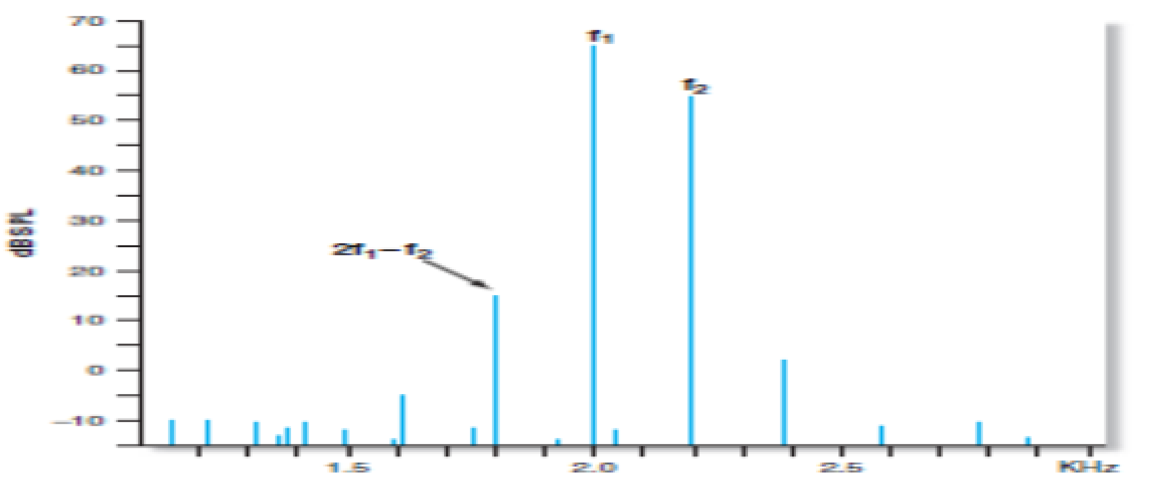

Figure 2.

Figure (2): DPOAEs show F 1 ,F 2 and 2F1-F2

Pass and refer criterion commonly used in screening and diagnostic OAEs methods is signal-to-noise ratios (SNRs: is the amplitude of the response signal over the noise floor for each frequency) more than 5 dB at 3/4 frequency, the most useful and clinically used EOAEs are TEOAEs and DPOAEs [10,11], so both TEOAEs and DPOAEs are used in; infant screening, pediatric assessment, cochlear function monitoring (ototoxicity and NIHL) and diagnostic applications hearing impairment that is caused by retrocochlear disorder, such as tumors impinging on eighth nerve or brainstem lesions affecting the central auditory nervous system pathways, also useful for evaluating patients with functional or nonorganic hearing loss[2,3,4]. When TEOAEs are present, hearing thresholds equal to or better than 20 dB HL would be predicted. TEOAEs are inevitably absent in cases with SNHL exceeding 40 dB HL . A mild hearing loss with thresholds ranging from 25 to 35 dB HL is considered the zone of uncertainty, where the interpretation of TEOAEs is not clear. The zone of uncertainty is wider in DPOAE recordings than in TEOAEs, ranging from 25 to 50-60 dB HL [6,7]. The SNR level of TEOAEs is significantly higher in female compared with male, but the SNR level of DPOAEs show no significant difference between female and male, OAEs change as a function of age, children have larger emissions than adults, but have lower levels than infants [12,13]. Some organizations recommend screening of school-age children, pointing out the risks associated with undetected hearing loss. There is also some controversy on what screening method is the best. Some studies recommend OAEs, while others suggest PTA [12,13].

Aims of the study

1. To determine if the TEOAE and DPOAEs methods would results in equivalent pass/refer rates in normal hearing.
2. To compare SNR of TEOAE with SNR of DPOAE to determine which methods give strong emission.
3. To describe possible ear asymmetry and gender effects in TEOAEs and DPOAEs for all frequencies as normative data.

Subjects and Method

This was a prospective comparative study conducted in Basrah, Iraq. Four different schools were selected for data collection. The participating students were first-grade pupils (six years old). Data collection was conducted over a period of three months, from February 2025 to May 2025.

An isolated room and the school library were used to perform the testing procedures. A total of 130 students participated in this study (65 males and 65 females), and overall, 260 ears were examined.

All subjects underwent clinical otologic and audiological evaluations, including medical history taking, otoscopy, tympanometry, TEOAEs, DPOAEs, and threshold pure-tone audiometry.

Criteria of exclusion from the study included:

(1) history of active or recent otologic disease

(2) history of ear surgery or head injury

(3) past exposure to ototoxic drugs or any other risk factor for hearing impairment;

(4) abnormal otoscopical examination

(5) abnormal tympanogram

(6) presence of hearing loss.

Standard audiometric procedures were applied and the pure tone thresholds of each ear at frequencies of 0.25, 0.5, 1, 2, 3, 4, and 8 kHz were measured. Subjects were considered to have a hearing loss if any threshold between 250 Hz and 8000 Hz exceeded 25 dB HL [1,2], A Pure tone audiometer was used with a standard supra aural TDH-39 headphones to detect hearing threshold at 20 dB for all the subjects, the responses to the signals typically include a hand raise. The audiometer devices were manufactured by SEMENS Company – Denmark; Serial Numbers are: 157323, with specifications arranged according to American National Standards Institute for measurements (ANSI s3.6 1996).

The portable tympanometry (226 Hz) were used manufactured by SEMENS Company – Denmark; Serial Numbers are: 160351 and only normal result was included which is type (A) tympanometry [10].

TEOAEs and DPOAEs were performed using a ERO.SCAN MIACO device for screening, TEOAEs frequency include (1500, 2000,2500,3000,3500, and 4000 Hz), the stimulus intensity tone burst 80-85 dB SPL. DPOAEs include (2000, 3000, 4000 and 5000 Hz), the stimulus intensity F2 55 dB SPL and F1 65 dB SPL, Pass and refer criterion were SNR more than 5 dB at 3/4 frequency [10].

Statistical analysis

ISSN 3063-8186 (online), https://ijhsm.umsida.ac.id, published by Universitas Muhammadiyah Sidoarjo

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All patients' data entered using computerized statistical software; Statistical Package for Social Sciences (SPSS) version 30 was used. Descriptive statistics presented as (mean ± standard deviation) and frequencies as percentages. Kolmogorov Smirnov analysis verified the normality of the data set. Multiple contingency tables conducted and appropriate statistical tests performed independent sample t-test was used to compare between two means. In all statistical analysis, level of significance (p value) set at ≤ 0.05 and the result presented as tables and/or graphs.

Results

A total of 130 school aged children were included in present study. Males were equal to females, 50% male and 50% female. All these findings were shown in figure (7).

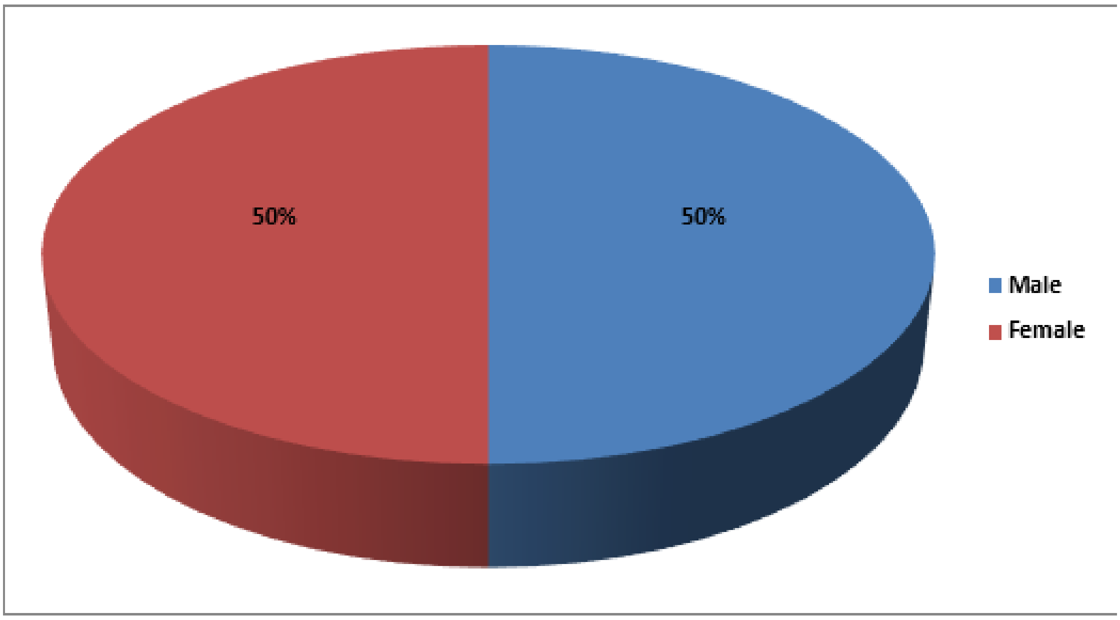

Figure 3.

Figure (7): Gender distribution.

Table 1 : TEOAEs and DPOAEs out c ome for pupils.

Variable	**No.**	**%**
	TEOAEs	
Pass	130	100.0
Refer	0	-
Total	130	100.0
	DPOAEs	
Pass	130	100.0
Refer	0	-
Total	130	100.0

Table 1.

Table 2: SNR distribution according to TEOAEs and DPOAEs.

SNR	**TEOAEs Mean±SD**	**DPOAEs Mean±SD**	**t-test**	**P**
2 KHz	7.1±4.4	19.9±8.1	22.2	<0.001
3 KHz	5.7±4.2	23.1±6.8	34.7	<0.001
4 KHz	3.5±4.4	21.7±5.9	39.6	<0.001

Table 2.

Table 3 : SNR distribution according to gender for TEOAEs.

SNR	**Male Mean±SD**	**Female Mean±SD**	**t-test**	**P**
1.5 KHz	8.2±4.4	7.6±5.1	0.9	0.3
2 KHz	7.5±4.3	6.6±4.4	1.5	0.1
2.5 KHz	6±3.7	6.3±3.7	0.5	0.5
3 KHz	5.3±3.9	6.2±4.4	1.6	0.09

ISSN 3063-8186 (online), https://ijhsm.umsida.ac.id, published by Universitas Muhammadiyah Sidoarjo

3.5KHz	5.1±3.7	6.1±4.9	1.7	0.08
4 KHz	3.4±3.9	3.5±4.9	0.3	0.7

Table 3.

Table 4: SNR distribution according to ear for TEOAEs.

SNR	Right Mean±SD	Left Mean±SD	t-test	P
1.5 KHz	7.7±4.8	8±4.7	0.5	0.5
2 KHz	7.2±4.7	6.9±4.1	0.4	0.6
2.5 KHz	6.5±3.5	5.8±3.8	1.4	0.1
3 KHz	5.4±4.1	6.1±4.2	1.4	0.1
3.5KHz	5.7±4.4	5.5±4.3	0.3	0.7
4 KHz	2.6±4.2	4.3±4.5	3.0	0.002

Table 4.

Table 5 : SNR distribution according to gender for DPOAEs.

SNR	Male Mean±SD	Female Mean±SD	t-test	P
2 KHz	20.5±7.9	19.4±8.4	1.04	0.2
3 KHz	22.9±6	23.3±7.5	0.4	0.6
4 KHz	21±5.6	22.3±6.1	1.7	0.08
5 KHz	20.6±6.8	22.3±7.6	1.9	0.05

Table 5.

Table 6 : SNR distribution according to ear for DPOAEs.

SNR	Right Mean±SD	Left Mean±SD	t-test	P
2 KHz	19.6±8.7	20.2±7.6	0.5	0.5
3 KHz	22.3±7.5	23.8±5.9	1.7	0.08
4 KHz	21.5±5.7	21.8±6.1	0.4	0.6
5 KHz	21.2±7.2	21.7±7.4	0.5	0.5

Table 6.

Discussion

The present study discussed relation between TEOAE and DPOAE normal hearing children, for which a few only published studies exist.

Our study revealed that there is no significant difference in pass/ refer between TEOAEs and DPOAEs in normal hearing children, the percentage of TEOAEs pass is 100% among children with normal hearing threshold and the percentage of DPOAEs pass is 100% among children with normal hearing threshold. As shown in table (1). This agreed with the result obtained by (Marilyn Dille[16],Theodore J Glattke[17] and Brian R..Eral 2007[18]), in which there were no significant pass/refer differences found between the TEOAEs and DPOAEs at any frequency in normal hearing threshold children.

We revealed from this study, also, that there is highly significant difference between SNR of TEOAES and SNR of DPOAEs in similar frequencies (2KHz , 3KHz , 4KHz); since the mean SNR of the whole ears for TEOAEs at 2KHz is 7.1 and the mean SNR of the whole ears for DPOAEs at 2KHz is 19.9 and with P.value < 0.001. The mean SNR of the whole ears for TEOAEs at 3KHz is 5.7 and the mean SNR of the whole ears for DPOAEs at 3KHz is 34.7 and with P.value < 0.001. The mean SNR of the whole ears for TEOAEs at 4KHz is 3.5 and the mean SNR of the whole ears for DPOAEs at 4KHz is 39.6 and with P.value < 0.001. As shown in table (2). This contradict the result obtained by (Marilyn Dille[16],Theodore J Glattke[17] and Brian R..Eral 2007[18]), in which there is no significantly different between SNR of TEOAEs and SNR of DPOAEs measured at frequencies (2500, 3200 and 4000 Hz).

The difference in SNR between TEOAEs and DPOAEs this supposed to be related to mechanism and methods of OAEs generation; (Shera and Guinan, 1999 ;) proposed that the different categories of otoacoustic emissions arise predominantly from two fundamentally distinct mechanisms in the cochlea. These two mechanisms of generation involve either linear coherent reflection (active hair bundle movement of the hair cell sterocilia) or nonlinear distortion (Somatic motility of OHCs) [7]. These fundamental processes are assumed to produce either primarily reflection source (i.e.TEOAEs), or distortion source (i.e.DPOAEs) emissions [8], [15]. Also in DPOAEs the stimulus is two sound (tones) of long duration are applied to cochlea while in TEOAEs the stimulus is click (brief sound) [1,2]. In addition TEOAEs result from large frequency region of the cochlea there for detection and frequency content are influenced by the status of whole cochlea , while DPOAEs generated by more specific area [7] .

Also our study reveal; There were no significant differences between males and females regarding SNR of TEOAEs of different frequencies (1.5, 2, 2, 3, 3.5,4 KHz). All these findings were shown in table (3). This contradict the result obtained by (Pavlovčinová G[12], Jakubíková J[13], Trnovec T[14]), in which significant differences were observed between SNR TEOAEs at frequencies (1, 1.5,2,3,4 KHz) in female than male.

Also our study reveals No significant differences were observed between right and left ear regarding SNR of TEOAEs at frequencies (1.5, 2, 2.5, 3, 3.5Hz) (p>0.05). This agreed with result obtained by (Pavlovčinová G[12], Jakubíková J[13], Trnovec

T[14]), But there was a significant differences between right and left ear SNR of TEOAEs at 4 KHz. (p=0.01). This contradict with result obtained by (Pavlovčinová G[12], Jakubíková J[13], Trnovec T[14]), in which no differences between right and left ear SNR of TEOAEs at 4 KHz. (. All these findings were shown in table (4).

our study reveals also; there is no significant differences were observed between males and females regarding SNR of DPOAEs at frequencies (2, 3, 4 Hz) for DPOAEs (p>0.05). This agreed with result obtained by (Pavlovčinová G[12], Jakubíková J[13], Trnovec T[14]), But there was a significant differences were observed between males and females regarding SNR of DPOAEs at 5 KHz (p=0.05). This contradicts with result obtained by (Pavlovčinová G[12], Jakubíková J[13], Trnovec T[14]), in which no significant differences were observed between males and females regarding SNR of DPOAEs at 5 KHz. All these findings were shown in table (5).

Our study reveals also; there is no significant differences were observed between right and left ear regarding SNR of DPOAEs at frequencies (2, 3,4,5 KHz) (p>0.05). This agreed with result obtained by (Pavlovčinová G[12], Jakubíková J[13], Trnovec T[14]). All these findings were shown in table (6).

The cause of gender and side of ear affection is related to the differences in the efferent inhibition delivered to individual cochlea originate from the cortex and developed in the 1st trimester of pregnancy [12].

Conclusion

1. TEOAEs and DPOAEs are reliable, objective and useful tests of the cochlear status; the percentage of pass is 100% in both methods in normal hearing children.
2. The SNR of DPOAEs is significantly higher than SNR of TEOAEs at similar frequencies (2, 3, 4 KHz) this indicates DPOAEs can use even in noisy environment.
3. There is no any relation with gender and side of the ear (right or left) in test children with TEOAEs and DPOAEs at most frequencies and this consider as normative data.
4. SNR of TEOAEs of left ear is significantly higher than right ear at 4 KHz.
5. SNR of DPOAEs of female is significantly higher than male at 5 KHz.

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