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RELATIONS OF RACE AND GENDER TO DISTORTION PRODUCT OTOACOUSTIC EMISSIONS

By

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ABSTRACT

RELATIONS OF RACE AND GENDER TO DISTORTION PRODUCT OTOACOUSTIC EMISSIONS

By

LARA L. GINGERICH

There is presently considerable promise for the use of distortion product otoacoustic emissions (DPOAE) as an audiological diagnostic tool. The purpose of this study was to compare DPOAEs among racial groups and gender groups in order to improve its clinical applicability. There was a need also to establish normative DPOAE data using a commercially available instrument. The present investigation was designed to answer the following questions: (1) Are there significant differences in DPOAEs recorded across different racial groups? (2) Are there significant differences in DPOAEs recorded between different genders? Participants included persons from three different racial groups: Asian, Black and White. The gender question was answered using White men and White women. There were no significant differences for DPOAEs between the various racial groups. There were, however, significant differences between gender for DPOAE amplitude. A significant difference was observed for ear canal volume between the two genders. Thus, the gender differences in DPOAEs may be related to the larger ear canal volumes measured in men as compared to women. In addition, an increase in DPOAEs was observed also when SOAEs were present. These results are consistent with prior studies in which amplitude differences were observed between genders. Thus, gender effects may need to be taken into account when establishing normative data for clinical audiologic purposes.

This is dedicated to my Parents who have taught me that strength, determination and perseverance are the underlying keys to success, and to Dr. Neil West whose medical expertise saved the life of a very sick little girl in May of 1976.

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CHAPTER I

INTRODUCTION

Otoacoustic emissions (OAEs) are acoustical responses that originate from a normal functioning organ of Corti. They can be detected in the external auditory meatus when the middle ear system is normal (Kemp, 1996). Brownell (1990) defined OAEs as a normal byproduct of the outer hair cells of the cochlea that are generated in response to an acoustic stimulus, or in the case of spontaneous OAEs (SOAEs), occur without acoustic stimulation. OAEs were first discovered by Kemp in 1978, although Gold had published a theoretical treatise on this topic in 1948. Since their discovery, OAEs have elicited the curiosity of scientific researchers, as well as clinicians, of the possibility that they may be used for research and clinical purposes. At the present time, there is considerable focus on the clinical utility of OAEs in audiologic practice.

Otoacoustic Emission Pathway

OAEs originate in the cochlea when energy is produced in response to acoustical-mechanical stimulation, or occur inherently in the normal functioning cochlea (e.g., SOAEs). The energy travels from the hair cells of the cochlea to the oval window, across the ossicular chain, thus vibrating the tympanic membrane and causing an acoustical wave to radiate out into the external auditory canal (Lonsbury-Martin and Martin, 1990). Kemp (1996) stated that OAEs are not electrical in nature, but are vibratory, and are created by the motion of the eardrum driven by the cochlea through the middle ear chain. Miniature microphones placed into the external auditory canal are used to detect OAEs. The recording microphone converts the vibratory energy into an electrical impulse and is processed via computer analysis (Kemp, 1996).

Given that OAEs are not very high in amplitude, Kemp (1996) stated that OAEs would perhaps go undetected if the ear canal was not acoustically sealed with a probe. That is, closing off the ear canal is essential for a more efficient system for compressing and rarefying the trapped air that would otherwise escape from the ear canal. Measurement of OAEs depend also on the condition of the middle ear cavity. The middle ear must function normally in order to accurately transmit these low energy signals to the outer ear canal. If middle ear pathologies exist, OAEs are most likely to be absent (Glattke and Kujawa, 1991). Measurements of otoacoustic emissions are non-invasive and do not require active patient participation. They do, however, require that the person being tested sit quietly so as not to introduce any unnecessary bodily noise, thus, preventing accurate recordings of the emissions.

Types of Emissions

Emissions can be classified into two different, basic classes. They may occur spontaneously (SOAEs) or in the presence of an evoking acoustic stimulus (EOAEs). Bright (1996) defined SOAEs as tonal signals of very low levels that can be recorded in the external ear canal without the use of any evoking stimulus. The prevalence of recorded SOAEs varies depending on the instrumentation that is used (Bright, 1996). Martin, Probst, and Lonsbury-Martin (1990) stated that SOAEs are present in approximately 50% of normal hearing humans. Bright (1996) further stated that recent data suggest that the prevalence of SOAEs is as high as 72% in persons with normal hearing. In addition, it has been found that women exhibit a higher prevalence of SOAEs than men (Bilger, Matthies, Hammel and Demorest, 1990; Martin et al., 1990; Whitehead et al., 1993).

Gender differences as well as racial differences have been reported for SOAEs. Whitehead et al. (1993) found significant differences in the SOAEs among three racial groups. They found that Black individuals exhibited more SOAEs than either Asian or White individuals. In addition, they noted a trend in which both the total number of SOAEs and the average number of SOAEs per emitting ear increased with greater skin pigmentation. They attributed their findings to different middle-ear conduction properties between racial groups, specifically, differences in tympanometric gradient and ear canal volume. The investigators acknowledged, however, that further study of these differences was warranted. Although there is extensive literature on SOAEs, they are not very useful clinically due to the lack of control over the frequency of the response and the highly variable prevalence rate.

While SOAEs have not been found to be totally applicable in the clinic, EOAEs, nevertheless, serve several clinical applications. There are currently three types of EOAEs, transient evoked otoacoustic emissions (TEOAEs), stimulus frequency otoacoustic emissions (SFOAEs), and distortion product otoacoustic emissions (DPOAEs). There are notable differences among these classifications as to stimulus parameters, latency of the response, and the degree to which a hearing loss can be reliably detected.

Transient Evoked Otoacoustic Emissions (TEOAEs)

Transient evoked otoacoustic emissions (TEOAE) are aptly named for the stimulus that is involved in its procedure. The stimulus consists of a transient acoustic signal (e.g., click or short tone burst) and the response is recorded over a specific analysis time of post-stimulation. The TEOAE analysis is based on a fast Fourier transform of the response. TEOAEs are restricted to frequencies from approximately 400 - 6000 Hz, and are absent in patients with a hearing loss greater than 30 dB HTL (Lonsbury-Martin et al., 1991). TEOAEs have a response-latency of approximately 5-20 ms from the time of the stimulus and the response of the outer hair cells. In an earlier paper, Lonsbury-Martin and Martin (1990) attributed the lag in time to a specific region within a hair cell that responds to the evoking stimulus. Audiologists have found TEOAEs to be a very useful screening tool for hearing impaired neonates, and in individuals who are unable or unwilling to participate in conventional audiometric procedures.

Stimulus Frequency Otoacoustic Emissions (SFOAEs)

Stimulus Frequency Otoacoustic Emissions (SFOAEs) were explored as a possible option for another test of cochlear function. The stimulus consist of a low-level pure tone of continuous duration (Martin et al., 1990). The response to this stimulus is recorded by slowly sweeping the frequency of the stimulus tone across a range of from approximately 1000-2000 Hz (Lonsbury-Martin, Whitehead and Martin, 1991). SFOAEs, however, are difficult to measure since the responses are embedded in the stimulus. As SFOAEs were explored further, it was found that they are very similar to TEOAEs. The similarities occurred within specific frequency regions and at the level at which the responses occurred. Due to the difficulty in measuring and interpreting SFOAEs, as well as the similarity of SFOAEs to TEOAEs, SFOAEs were determined to be a redundant test of cochlear function.

Distortion Product Otoacoustic Emissions (DPOAEs)

Distortion Product Otoacoustic Emissions (DPOAEs) are another type of evoked

OAE. The stimuli used to elicit DPOAEs are pure tones. What makes the DPOAE different from the TEOAE, other than the stimuli being pure tones, is that two tones are introduced to the cochlea simultaneously. The two tones create an intermodulation distortion response in which the signals are mechanically combined within the cochlea. The response is not an exact replica of the stimulus, since it includes components that are not present in the original stimuli (Lonsbury-Martin, Martin and Whitehead, 1996). The pure tone stimuli that are used as eliciting stimuli are known as the "primary" tones. Lonsbury-Martin et al. (1996, p.83) described these tones and their distortion products.

> "...The lower-frequency pure tone is referred to as the f_1 'primary', and its [acoustic] level as L_1; and the higher frequency pure-tone is referred to as the f_2 'primary', and its [acoustic] level, as L_2. The primaries are related in frequency in that the frequency separation of f_2 from f_1, commonly called the f_2/f_1 'ratio', is typically around f_1 x 1.2 (i.e.: the primary tones are within one-third octave of each other). The most frequently measured acoustic intermodulation-distortion product is at the frequency $2f_1$-f_2 (i.e.: the cubic difference tone), although the cochlea produces concurrent DPOAEs at other frequencies (e.g., f_2-f_1, $2f_2$-f_1, $3f_1$-$2f_2$, etc.)."

It has been demonstrated that $2f_1$-f_2 yields the largest emission in humans and other mammals, which is why it is used as the defining distortion product (Lonsbury-Martin, Whitehead and Martin, 1991). The distortion product emission occurs at 60-70 dB below the level of the evoking stimuli (Lonsbury-Martin et al., 1996). The DPOAE, as well as other OAEs, necessitate measurement by a small microphone placed in the ear canal. DPOAEs can be detected in a frequency range from approximately 500 to 8000 Hz and are absent in patients with hearing loss greater than approximately 50 dB HL (Lonsbury-Martin et al., 1991).

While otoacoustic emissions can be interpreted as evidence of a normal functioning cochlea (i.e., outer hair cell function), they are not a measure of hearing sensitivity. Without knowing of an individual's actual hearing threshold, only a hypothesis can be made that pertains to threshold. Current applications of OAEs include use as a screening tool in neonatal wards, screening for cochlear function while an individual is taking ototoxic medication, and confirmation of pseudohypacusis.

Instrumentation

Instrumentation for DPOAEs is commercially available from a variety of manufacturers (e.g., Bio-Logic Systems, Grason-Stadler Inc., Madsen Electronics, Mimosa Acoustics and Otodynamics Ltd.). Kemp presently holds the patent for TEOAEs, which can only be found on the commercially available system from Otodynamics Ltd. A few studies have used commercially available equipment to collect data (Gorga et al., 1997; Hornsby et al., 1996; Vinck et al., 1996). Other investigators have used experimentally built systems to collect and report OAE data (Glattke and Kujawa, 1991; Lasky, Snodgrass, and Hecox, 1994; Lonsbury-Martin, Harris, Stagner, Hawkins and Martin, 1990; Lonsbury-Martin, McCoy, Whitehead, and Martin, 1993). While a few investigators (Gorga et al., 1997; Hornsby et al., 1996; Vinck et al., 1996) conducted well-controlled studies, there was no information about the gender or race of the subjects. More normative studies of DPOAEs are needed as pertains to race and gender.

CHAPTER II

REVIEW OF THE LITERATURE

Since the discovery of otoacoustic emissions (OAEs) in 1978 by Kemp, investigators have identified clinical applications for these measurements. Studies have attempted to reveal new information regarding cochlear function and the role of hair cells in hearing (Avan, Bonfils, Loth, Teysson and Menguy, 1993; Brownell, 1990; Kemp, 1986; Wake, Anderson, Takeno, Mount and Harrison, 1996), in addition to understanding the process of OAE generation (Lonsbury-Martin, Whitehead and Martin, 1993). Furthermore, there is a wealth of literature about possible clinical applications that include, but are not limited to, newborn hearing screening, monitoring of ototoxic drug effects, and the quantification of cochlear function. The first step in the use of OAEs is to identify pathology as related to is the definition of normal OAEs.

Normative Data

Several investigators have collected information on adult human subjects with respect to normative data, but two problems have emerged (Gorga, Neely, Ohlrich, Hoover, Redner and Peters, 1997; Vinck, De Vel, Xu and Van Cauwenberge, 1996). First, the normative data were based on human versus animal results and only age effects, if any, were included. Second, the measurements were made in sound treated rooms that did not account for ambient room noise. Emissions that are recorded clinically are most likely to be recorded in a more reverberant or less-controlled acoustically environment.

Gorga et al (1997), Hornsby, Kelly and Hall (1996), and Vinck et al. (1996) used commercially available equipment to collect normative data on adults. Gorga and his colleagues (1997) used the Bio-Logic Scout system, while Hornsby et al. (1996)

compared five systems (Bio-Logic Scout, Grason-Statler 60, Madsen Celesta, Mimosa, and Virtual 330). Both studies measured DPOAE responses using normal hearing subject populations. Vinck et al. (1996) used the Otodynamics Ltd. system to collect DPOAE data also on a normal hearing population. Although all studies were well-controlled, none of the investigations considered possible racial and gender effects among their respective subject population.

There are several studies suggesting that race and gender may have significant effects on otoacoustic emissions, which may affect demonstrated normative data (Cacace, McClelland, Weiner and McFarland, 1996; Gaskill and Brown, 1990; Lonsbury-Martin, Whitehead and Martin, 1991; Moulin, Collet, Veullet and Morgon, 1993; Whitehead, Kamal, Lonsbury-Martin and Martin, 1993). None of these studies used comerically-available equipment.

In light of these shortcomings, the present investigation was undertaken to explore and answer the following questions: (1) Are there significant differences in the DPOAEs recorded in different racial groups? (2) Are there significant differences between gender?

Race and Gender Effects

Overfield (1995) stated that there are three levels from which to view human variation: race and sex, race and age, and individual. Brues (1977, p.1) stated that race is defined as " a division of a species which differs from other divisions by the frequency with which certain hereditary traits appear among its members." Webster's Desk Dictionary (1990) defines race as "(1) A division of the human species characterized by a more or less distinctive combination of physical traits that are transmitted in descent. (2)

A group of tribes or peoples forming an ethnic stock. (3) Any group or class of persons." These definitions suggest possible differences may be related to clinical instrumentation used to identify cochlear function or pathology.

The earliest audiologic studies that identified gender and racial differences dealt with air-conducted pure-tone threshold measures. Corso (1959) investigated age and gender differences in air conducted pure-tone thresholds. He found that women have more sensitive hearing than men. Post (1964) compared the hearing sensitivity between Blacks and Whites. He found that only adult subjects exhibited differences in threshold sensitivity, and that Blacks exhibited better thresholds than Whites at frequencies above 2000 Hz. He suggested that these difference were perhaps due to hereditary factors. However, occupational environment and other subject factors were not taken into account.

Shepherd, Goldstein and Rosenblüt (1964) also found racial differences in auditory sensitivity measured using the method-of-limits and Békèsy audiometry. While the method-of-limits indicated that White men and White women had better thresholds than their respective Black counterparts at frequencies of 1000 and 2000 Hz, Békèsy audiometry identified no significant racial differences among men at 1000 Hz. White women demonstrated significantly better thresholds across frequencies than Black women. The limitations of this study were difference in sizes of the groups studied and the educational level of participants was a variable in one group, but not the other. They concluded that the threshold differences of the women could be attributed to a more sensitive auditory system among White women, regardless of the socio-economic level or cultural habits of the group.

Royster, Royster and Thomas (1980, p. 553) reported on pure-tone thresholds during industrial hearing testing in North Carolina. They found significant effects on thresholds for both race and gender. They cited reasons for the differences by quoting others: "[differences] are due to 'actual inborn differences between the biophysical systems' rather than to cultural and environmental influences." Their findings thus indicated significant differences between the two groups. Groups with the most sensitive hearing (lowest thresholds) were Black women, followed by White women, Black men and White men. The difference in mean thresholds between Black and White men was between 10-20 dB for frequencies above 2000 Hz. In addition, the difference in mean thresholds between Black and White women was smaller and found to be between 5-10 dB for frequencies above 2000 Hz. The investigators stated that their findings concurred with those of Post (1964). Royster et al. (1980) cited also information from the National Health Survey of 1960-1962. The latter study analyzed thresholds of 7,700 subjects who were 18-79 years of age. They found that Black men had better mean thresholds than White men across frequencies from 500-6000 Hz. They further stated that Black women had better mean thresholds at 500, 1000, and 6000 Hz than White women. The actual differences in mean threshold values were not noted.

Racial differences in anatomical structure have been identified (Hajniš, Farkas, Ngim, Lee and Venkatadri, 1994). These investigators studied certain head and neck anatomical differences among three racial groups, Asian, Black, and White. Of the several measurements performed, the ones most relevant to the present study are those of the head and ears. The largest and longest sizes of the circumference and length of the head appeared among Blacks. The smallest and shortest dimensions were measured in the Asian population. For the width of the head, Asians exhibited the largest size, while Blacks exhibited the smallest. The pinnae were the most narrow among the Asian group, the longest among the White group, and the shortest and widest among the Black group. However, ear canal size and resonance characteristics of the external auditory canal were not investigated.

Two groups of investigators have studied differences in cochlear length. This may have implications for differences in DPOAEs between race and gender. Sato, Sando and Takahashi (1991) noted differences in cochlear length between genders. The authors studied the cochlea in the temporal bones of age-matched subjects for both male and female subjects. The ages of the individuals ranged from 1 day to 76 years. They found that the mean cochlear length for males was significantly longer when compared to the length in females. The cochlear length as a function of gender did not vary with postnatal age, prompting the investigators to conclude that the cochlea fully develops in-utero. This suggested that male neonates have a longer cochlear length than female neonates. These findings may explain why emissions are greater in amplitude among females than in males. That is, the travel time from the cochlea to the ear canal will have an impact on the emissions. This may perhaps manifest itself in the dampening of the emissions in males during the outward propagation of the waves to the outer ear canal.

Kimberly, Brown and Eggermont (1993) studied cochlear traveling time delay using DPOAE phase measurements. They found that there were gender differences in wave delay, with males exhibiting significantly longer delays than females. They too attributed this to the anatomical difference in cochlear length between genders, as noted by Sato et al. (1991). Differences in amplitude of the emission were not reported by

Kimberly et al. (1993).

There have been few studies on the effects of gender on DPOAEs. Gaskill and Brown (1990) compared the amplitudes of DPOAEs to auditory threshold measures of both men and women. They found that women exhibit larger amplitudes than men at frequencies from 1000-5000 Hz. These investigators found also similarities between auditory threshold and the DPOAE amplitude, stating that DPOAEs would be a good predictor of acoustical function. Moulin, Collet, Veuillet and Morgon (1993) also studied the effects of gender on DPOAEs. They found a significant difference in amplitude at only one frequency (2000 Hz). They stated that the emissions were of a lower amplitude when the person does not exhibit SOAEs. This suggests that SOAEs may enhance DPOAE amplitude at corresponding frequencies. Cacace, McClelland, Weiner and McFarland (1996) observed gender effects on DPOAEs across frequencies, confirming the results of Gaskill and Brown (1990) and Lonsbury-Martin et al. (1991). These investigators used the Otodynamics Ltd. ILO-92 commercial system for stimulus generation as well as for response recording, measurement and analyses.

Currently, there are data on gender effects but none on racial effects as related to DPOAE norms. However, one study did take race into account while investigating SOAEs (Whitehead, Kamal, Lonsbury-Martin and Martin, 1993). These authors reported significant differences in the occurrence of SOAEs between the two gender and the three racial groups studied. They noted that Black individuals exhibited more SOAEs than either the Asian or the White group. Black individuals emitted also more multiple SOAEs. Since SOAEs are thought to enhance DPOAE amplitude (Moulin et al., 1993), these racial and gender differences may also account for DPOAE differences. The present study will investigate the effects of gender and race of both SOAEs and DPOAEs in an attempt to further clarify this issue.

CHAPTER III

METHODS AND PROCEDURES

Subjects

The participants consisted of 40 normal hearing college-aged men and women. Each subject participated on a volunteer basis and were members of the Michigan State University Community. Four different groups were represented: Asian women, Black women, White women, and White men. Each group consisted of ten participants. These groups were chosen on the basis of past studies incorporating racial differences in measurement of certain parts of the head (Hajniš et al., 1994; Overfield, 1985) and differences found between SOAEs in different racial groups (Whitehead et al., 1993). Comparison of the gender factor was based on measurements made of subjects of the White group. Participants were between the ages of 18-35 years (mean = 23.03 years). The average age for the four groups were similar (Asian women = 25.2 years, Black women = 21.4 years, White women = 21.2 years, White men = 24.3 years). The test ear was counterbalanced among participants to ensure equal distribution of left vs. right ears. A typical test session lasted no more than 60 minutes.

General Experimental Protocol

Case History

All subjects completed a short case history to determine candidacy. The questions investigated ethnic heritage, age, gender, height, hearing health history, family history of hereditary hearing loss, significant noise exposure, history of significant middle ear infections, and any past or current ototoxic drug use.

Otoscopy

Each subject underwent otoscopy using a video otoscope (Jedmed 80999-000, Carrollton, TX). The otoscopic examination was performed to examine the conditions of the outer ear canal and to confirm that it was free of occlusion due to cerumen or foreign objects.

Middle Ear Testing

Tympanometry was performed using an immittance instrument to confirm normal middle ear function (Grason-Stadler Inc., model 33, Milford, NH). Each subject was seated in a comfortable chair and tests were performed in a quiet room. The immittance meter recorded, tympanometry, static admittance and equivalent ear canal volume (V_{ea}). Each subject exhibited normal values for all measurements (Margolis and Heller, 1987).

Audiometric Testing

Pure tone audiometry was performed to confirm that all participants demonstrated hearing within normal limits. Testing was performed a sound-treated booth (Industrial Acoustics Corporation, model 380, Bronx, NY). Each subject was seated in a comfortable chair and headphones (TDH-49/Mx41AR cushions) were placed over both ears. Each subject was instructed to listen to a pure tone and indicate audibility by raising their hand. Hearing thresholds were obtained at eight frequencies (250, 500, 1000, 2000, 3000, 4000, 6000, and 8000 Hz), using air-conducted pure tone stimuli. Hearing testing was performed using an audiometer (Grason-Stadler Inc., model 16, Milford, NH), obtaining thresholds in increments of 5 or 10 dB steps (Hughson-Westlake procedure). Hearing sensitivity was deemed normal when thresholds were better than 20 dB HL (ANSI, 1996).

Real Ear Measurements

A real ear unoccluded response (REUR) and a real ear occluded response (REOR) were obtained using the OAE probe tip as the occlusion device (Hearing Aid Test System Computer Controlled Real-Time Analyzer, Fonix 6500, Frye Electronics Inc., Tigard, OR; Probe Tip Variety Pack, cat. # GSI 1700-9960, Gordon Stowe & Associates, Wheeling, IL). These measurements demonstrated the resonance characteristics of individual ears across the frequencies from 1000-8000 Hz, and were used to compare the ear canal characteristics of each of the racial and gender groups. Each subject was seated in a comfortable chair in a quiet room. A Velcro strip was placed around the head of the subject and a small microphone was attached. A speaker was placed approximately one meter away from the subject at a 45° angle to the microphone. The microphone measured the amount of sound at the head and acted as the referent sound. A probe tube microphone was then inserted into the ear canal of the subject to record the resonance response with or without the emission probe tip inserted in the ear canal.

Distortion Product Otoacoustic Emission Testing Parameters

A commercially available EOAE instrument was used to measure DPOAEs (ILO92, Otodynamics Ltd., London, England, UK). The software program was controlled by a personal computer system (Zenith 486, St. Joseph, MI). The software is capable of managing stimulus generation as well as recording and analyzing subsequent emissions.

Two pure tone frequencies (f_1 and f_2) were delivered to the ear canal using a probe tip device (Probe Tip Variety Pack, cat. GSI 1700-9660, Gordon Stowe & Associates, Wheeling, IL). The stimuli were presented simultaneously to the external ear canal through separate speakers to ensure that mixing of signals did not occur prior stimulating the test ear. The two frequencies elicited emissions at approximately 1000, 2000, 4000, 6000 and 8000 Hz, to produce the cubic distortion product ($2f_1$-f_2).

DPOAE stimulus levels (L_1 and L_2, with $L_1 > L_2$) were selected so that emissions were elicited to unequal level stimuli as emission amplitude is larger to unequal intensity levels (Lonsbury-Martin et al., 1996; Sun, Kim, Jung and Randolph, 1996). Sun et al. (1996) noted also that emissions were more sensitive to cochlear dysfunction when the stimuli are of unequal levels. Thus, the pure tone stimuli were presented at L_1 = 65 dB SPL and L_2 = 55 dB SPL, a ratio of 1.22 (Gorga et al., 1997).

DPOAEs were recorded using the "DP-gram" format. This encompasses a wide stimulus frequency domain. For this study, each point of the DP-gram was obtained in 3 dB/per octave steps for the F_2 frequency between 1000 and 8000 Hz.

An emission was considered to be present if the response was ≥ 3 dB SPL greater than the noise floor (Martin et al., 1990). The "probe fit function" of the software assessed the fit of the probe in the ear canal to determine if the ambient noise level was sufficient for accurate measurements to occur. Unlike tympanometry, OAEs do not require a hermetic seal when obtaining emissions at or above 1000 Hz. In order to obtain accurate emissions for the purposes of this investigation, however, the probe was fit snugly into the ear canal in order to maximally decrease the noise floor. The depth of the probe was maintained constantly across all subjects to diminish variability of the data.

Spontaneous Otoacoustic Emission Testing Parameters

SOAEs were measured using the same commercially available equipment (ILO92). The probe used to measure DPOAEs remained in the ear canal for purposes of measuring SOAEs, and to keep the probe fit consistent. Measurement and frequency analysis of emissions were completed using the same software program. An emission was considered to present using the same criteria used for DPOAE measurements.

Data Analyses

Data were collected from racial and gender groups and were analyzed to identify effects due to these differences. Amplitude of DPOAEs were combined within racial and/or gender groups by frequency, and analyzed using the General Linear Model. Analysis of DPOAE response amplitudes over the 1000-8000 Hz frequency range at the distortion product intensity levels (65, 55 dB SPL) were performed in order to describe the "DP-gram" response. All other data analysis was completed using a one-way ANOVA. Statistical analysis of the DPOAE data was analyzed using SPSS (SPSS Inc., v.8.0, Chicago, IL). All other statistical analyses were computed using Minitab (Minitab Inc., 1996, State College, Pa). Mean data were subsequently graphed using Sigma Plot (Jandel Corporation, 6.0, San Rafael, CA).

Kerlinger (1964) stated that the use of parametric statistics is preferable over non-parametric statistics due to their increased power in finding significant differences. He defines power as the probability that the null hypothesis will be rejected when it is actually false. While parametric statistics are favorable, certain conditions must be met before being applied. According to McCall (1994), there are four assumptions underlying the use of the ANOVA: (1) the sample is made up of randomly chosen independent samples, (2) the groups of scores are independent of each other, (3) homogeneity of variance within the groups, and (4) each sample is drawn from a normal population. All conditions named were met in the present investigation prior to the use of the one-way ANOVA and the General Linear Model.

CHAPTER IV

RESULTS

There is considerable promise for the use of distortion product otoacoustic emissions (DPOAE) as an audiological diagnostic tool. The purposes of present study were to compare DPOAEs among different racial groups and gender using a commercially available instrument and to establish normative DPOAE data. This study explored and answered the following questions: (1) Are there significant differences in DPOAEs recorded in different racial groups? (2) Are there significant differences in DPOAEs between genders? Participants included individuals from three different racial groups: Asian, Black and White. The question about gender was answered by comparing DPOAE data between White men and White women.

Pure Tone Hearing Thresholds

Pure tone data were analyzed by a one-way ANOVA to determine whether there were significant differences in hearing thresholds between groups. There was a statistically significant difference between groups ($p < 0.05$) (see Figures 1 and 2). Post hoc testing using the Tukey pairwise comparison ($p < 0.05$, $df = 3$, $F = 4.39$) indicated that the difference existed at 6000 Hz between the men and all groups of women. There were no significant difference in threshold between the groups of women. While significant differences were observed between genders, each individual that was included in the study demonstrated hearing thresholds within normal limits.

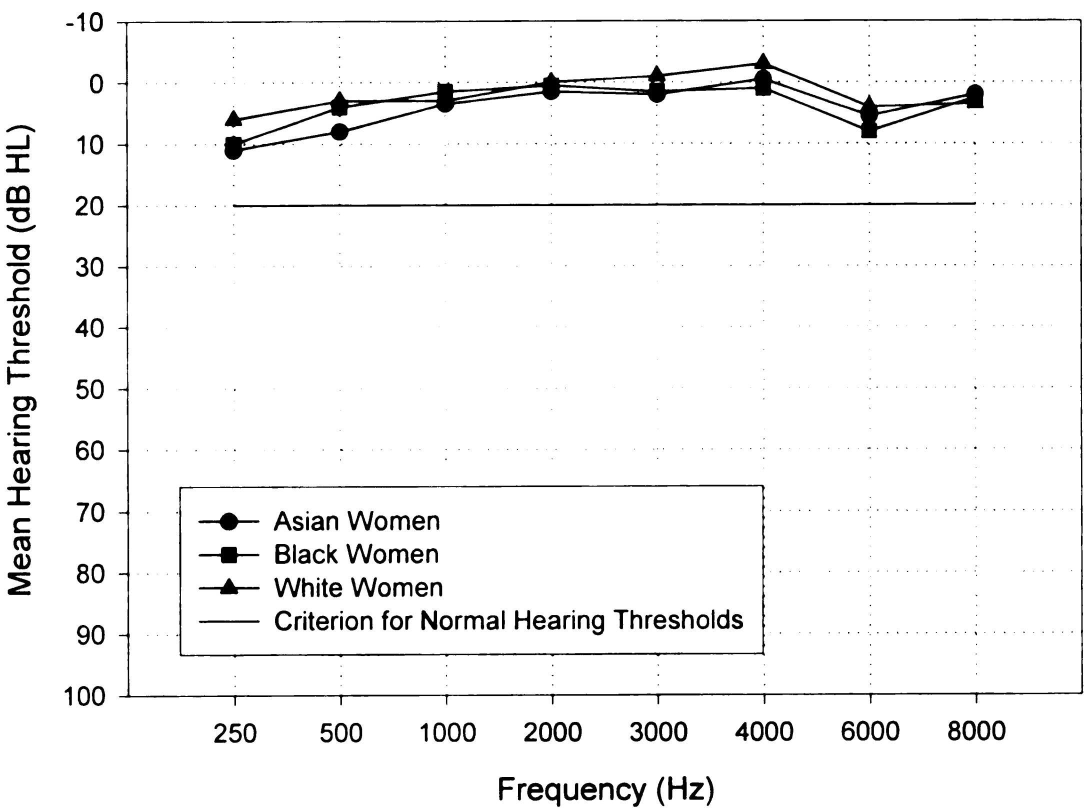

Figure 1. Mean pure tone hearing thresholds among racial groups of women.

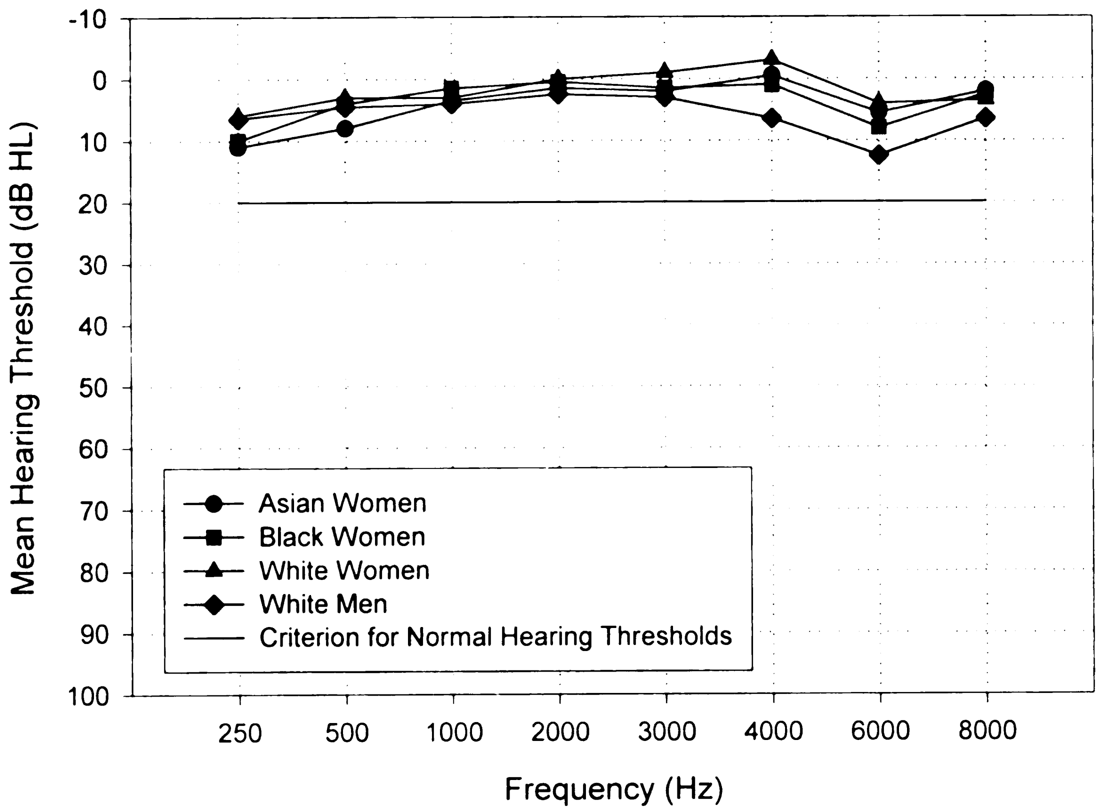

Figure 2. Mean pure tone hearing thresholds between men and women.

Equivalent Ear Canal Volume (V_{ea})

These data were analyzed for ear canal volume using a one-way ANOVA. Admittance values from tympanometric measurements were compared among the various racial groups of women. There were statistically significant differences between groups ($p < 0.001$, $F = 10.82$, $df = 3$) in equivalent ear canal volume (V_{ea}). Post hoc testing (Tukey pairwise comparison, $p < 0.05$) indicated a difference between men and all groups of women (see Figure 3). There were no differences between the groups of women.

Height

Analysis of height using one-way ANOVA demonstrated a significant difference between groups ($p < 0.001$). Post hoc testing (Tukey pairwise comparison) indicated a significant difference between men and women at $p < 0.05$ level (see Figure 4). There were no significant differences between the groups of women.

Distortion Product Otoacoustic Emissions

Of the 40 ears that were tested, each ear demonstrated definable emissions of similar configuration (see Figure 5). Measurement of these emissions progressed quickly, taking less than three minutes to complete. Data were recorded at nine response frequencies across all groups. The frequencies were 1184, 1477, 1868, 2368, 2996, 3748, 4724, 5957 and 7495 Hz. There was a statistically significant difference between groups ($p < 0.05$) (see Figure 6). Post hoc testing (Scheffé) isolated the difference to be between White men and all women at the distortion product frequency 4724 Hz (see Figure 7). There were no statistically significant differences among the racial groups of women.

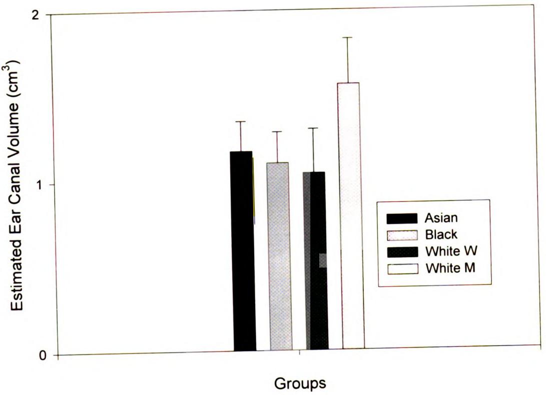

Figure 3. Equivalent ear canal volume for all groups, including standard deviation bars.

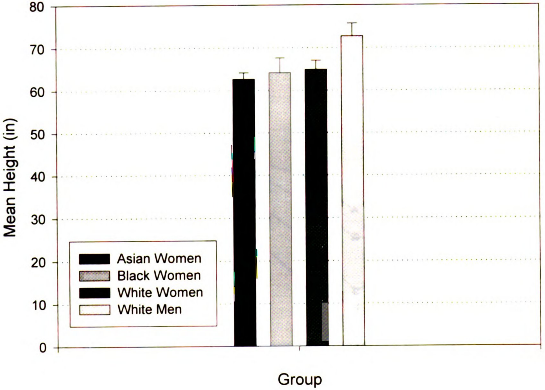

Figure 4. Mean height for all groups including standard deviation bars.

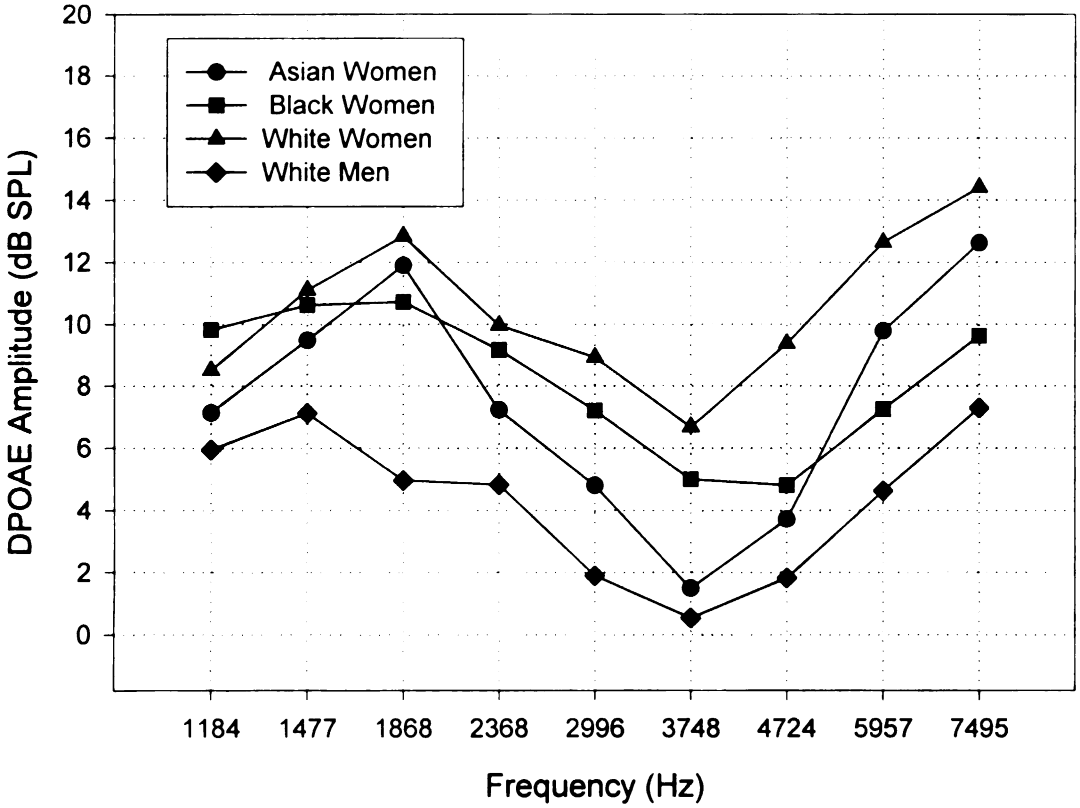

Figure 5. Mean DPOAE amplitude for all groups across frequencies.

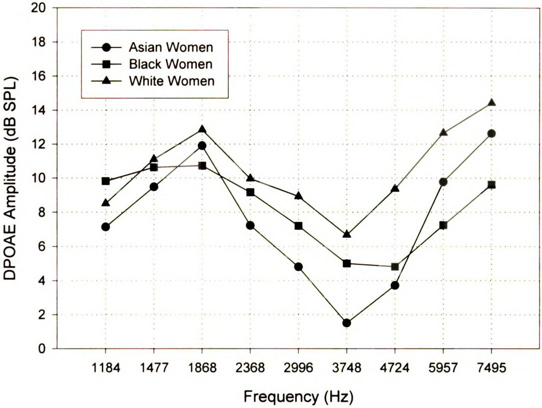

Figure 6. Mean DPOAE amplitude among racial groups of women.

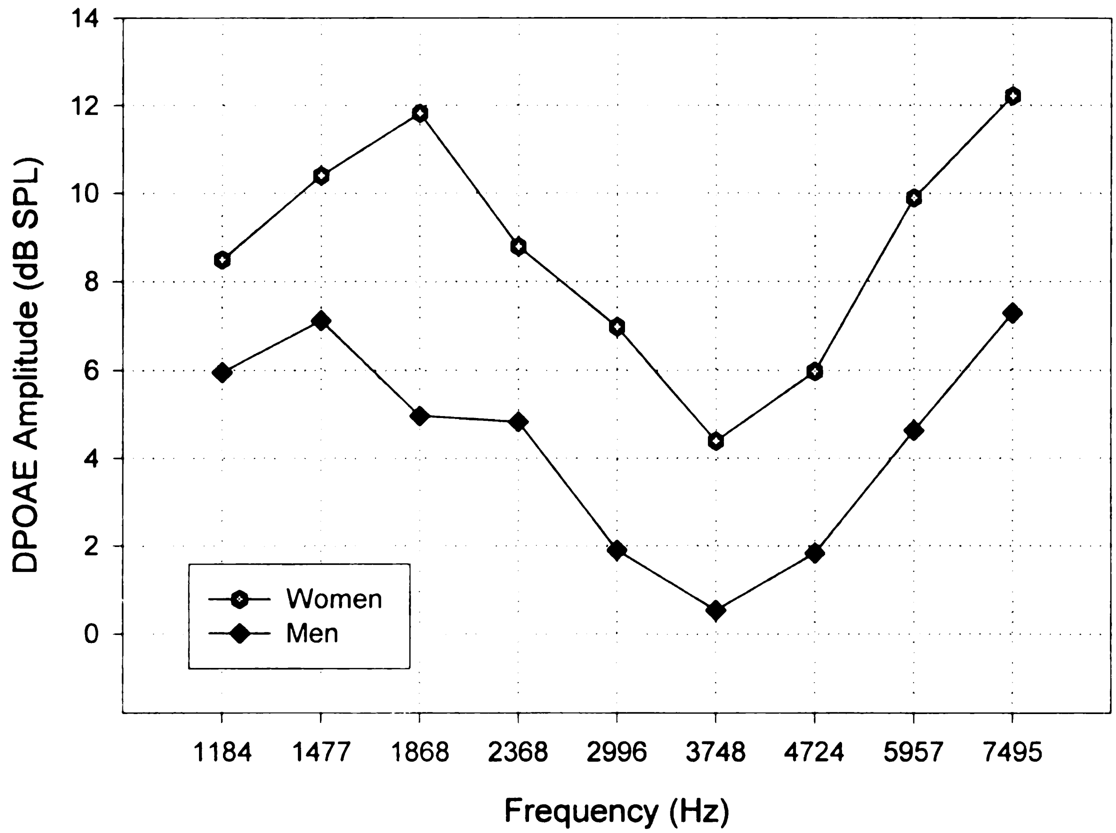

Figure 7. Mean DPOAE amplitude between men and women.

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In addition to the above analyses, the data were analyzed by accounting for the noise floor of the DPOAE responses (see Figure 8). This increased the emission amplitude for all frequencies.

Real Ear Unoccluded Response

Real ear unoccluded responses were analyzed by one-way ANOVA to determine differences in ear canal resonance. Statistical analysis revealed significant differences between groups ($p < 0.01$, $F = 4.67$, $df = 3$) (see Figure 9). Post hoc testing (Tukey pairwise comparison) found the differences to exist between men and all groups of women at 2000 Hz ($p < 0.05$) (see Figure 9). There were no statistically significant differences between the groups of women (see Figure 10). Upon closer examination at 2000 Hz, no significant difference is confirmed at this frequency (see Figure 11). At first glance, one may see a significant difference at 8000 Hz among the women; however, the difference did not reach statistical significance (see Figure 12).

Real ear occluded response measurement verified the probe fit in the ear canal. If resonance qualities of the ear canal decreased, the probe fit was considered adequate. Visual inspection of these data insured a good probe fit, thus, no further analyses seemed appropriate.

Spontaneous Otoacoustic Emissions

Of the 40 participants tested, 58% (23/40) exhibited SOAEs. Of the women, 70% (21/30) exhibited SOAEs at frequencies ranging from 745 Hz to 5301 Hz , and at levels from –30.2 dB SPL to 1.1 dB SPL (see Figure 13). The White men who exhibited SOAEs showed multiple emissions, i.e., more than one emission occurred across the frequency spectrum. Among the Asian women, six individuals exhibited SOAEs. Of this group, three of the six individuals exhibited multiple SOAEs, thus, four of the Asian women did not exhibit any SOAEs. Among the Black women, eight individuals demonstrated SOAEs, and seven of these exhibited multiple SOAEs. Among the White women, seven individuals demonstrated SOAEs, while five exhibited multiple SOAEs. Comparing the number of SOAEs present in each of the four groups, no statistically significant differences were found (see Figure 14). It is interesting to note, however, that among all responses, there was only one frequency match of the SOAEs to DPOAE responses. This occurred for the Black women at the frequency of 1477 Hz, with an amplitude of – 4.7 dB SPL. There were, what appear to be 14 close matches in frequency among all groups, with more matches among the women than among men due to the increased frequency of SOAEs in these groups (within 8-71 Hz of a DPOAE response). The majority of SOAEs occurred within the middle to lower frequency range (1000-2000 Hz) (see Figure 13). . Additionally, a comparison of DPOAE amplitude was made between individuals who have SOAEs and those who did not exhibit such a response (see Figure15). This indicates that DPOAEs are enhanced when SOAEs are present.

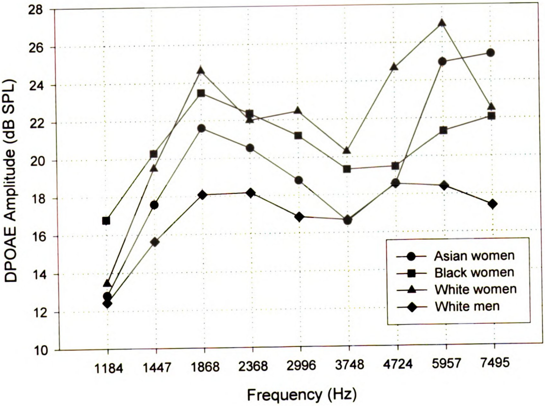

Figure 8. Mean DPOAE amplitudes for all four groups across all frequencies Accounting for the noise floor.

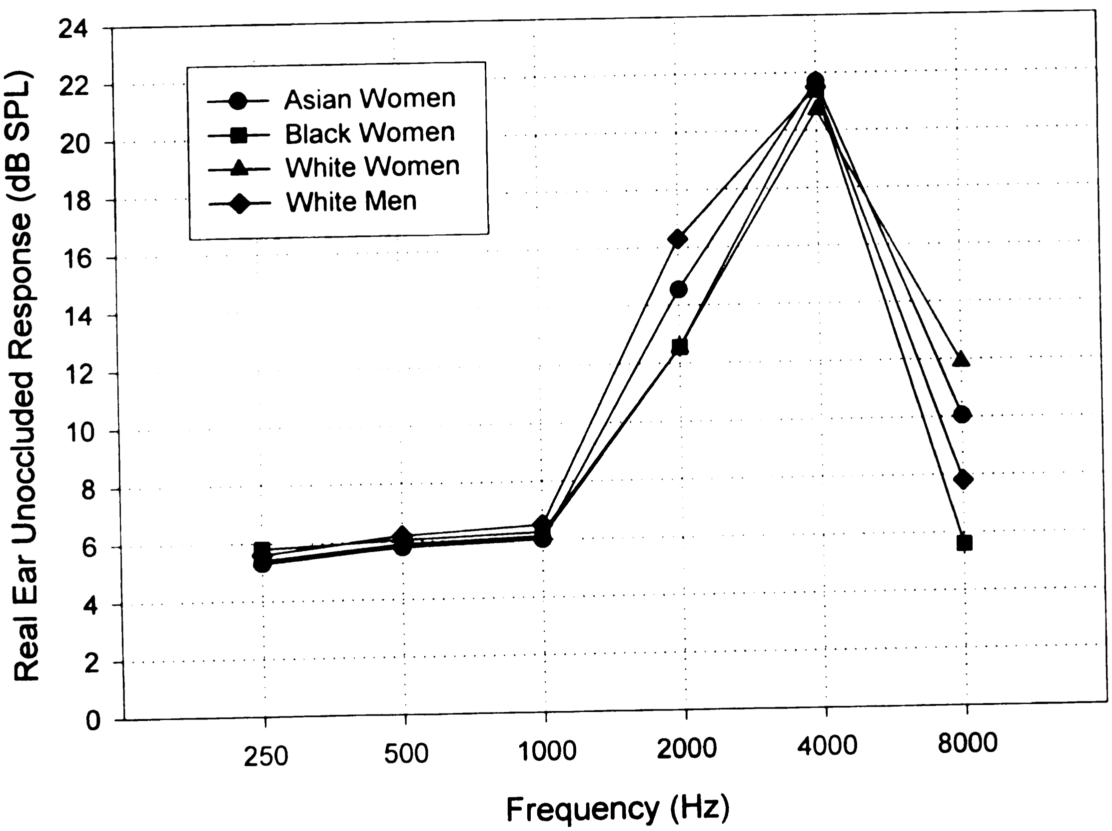

Figure 9. Mean real ear unoccluded responses among all four groups.

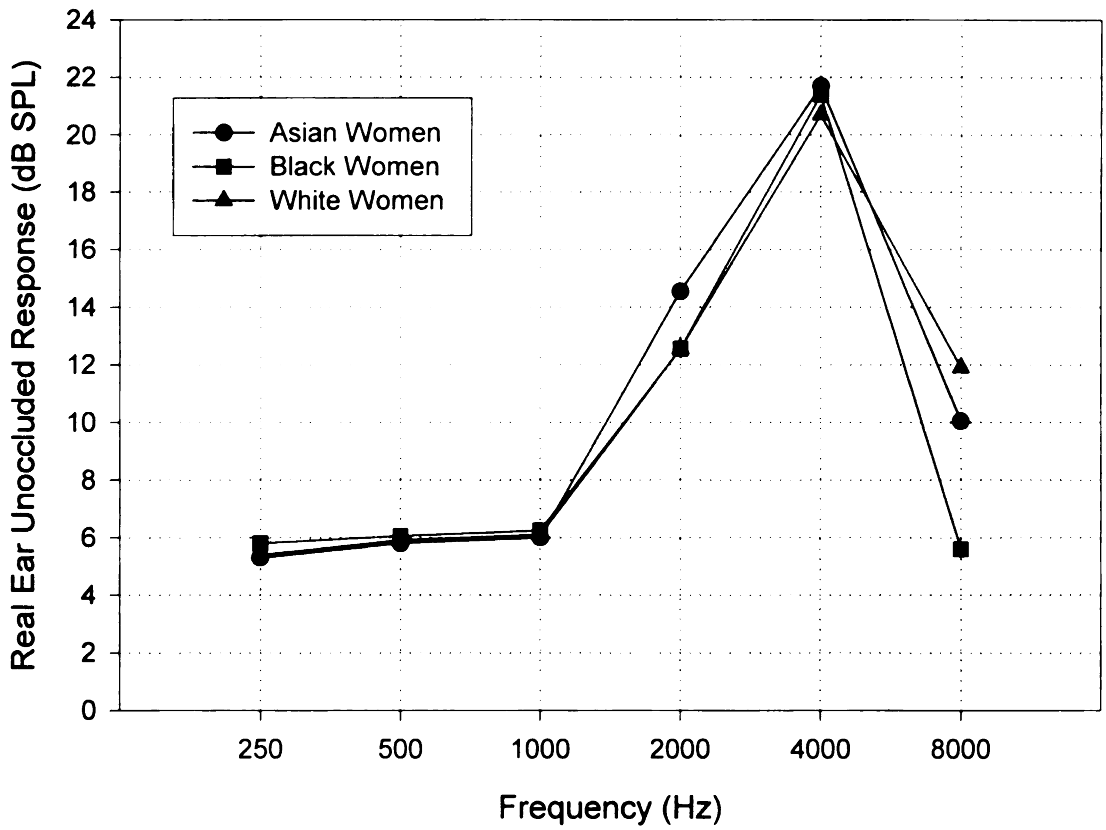

Figure 10. Mean real ear unoccluded response among all racial groups of women.

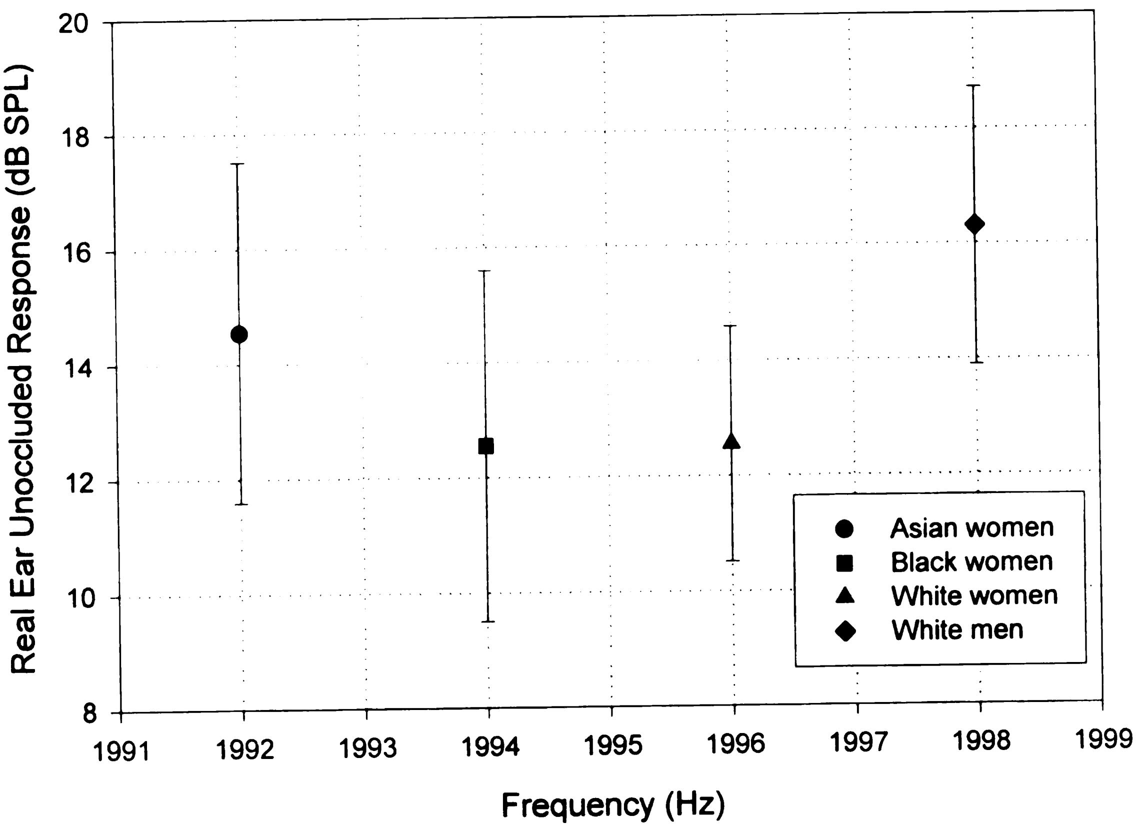

Figure 11. REUR response of all four groups at 2000 Hz, data points are offset for greater clarity.

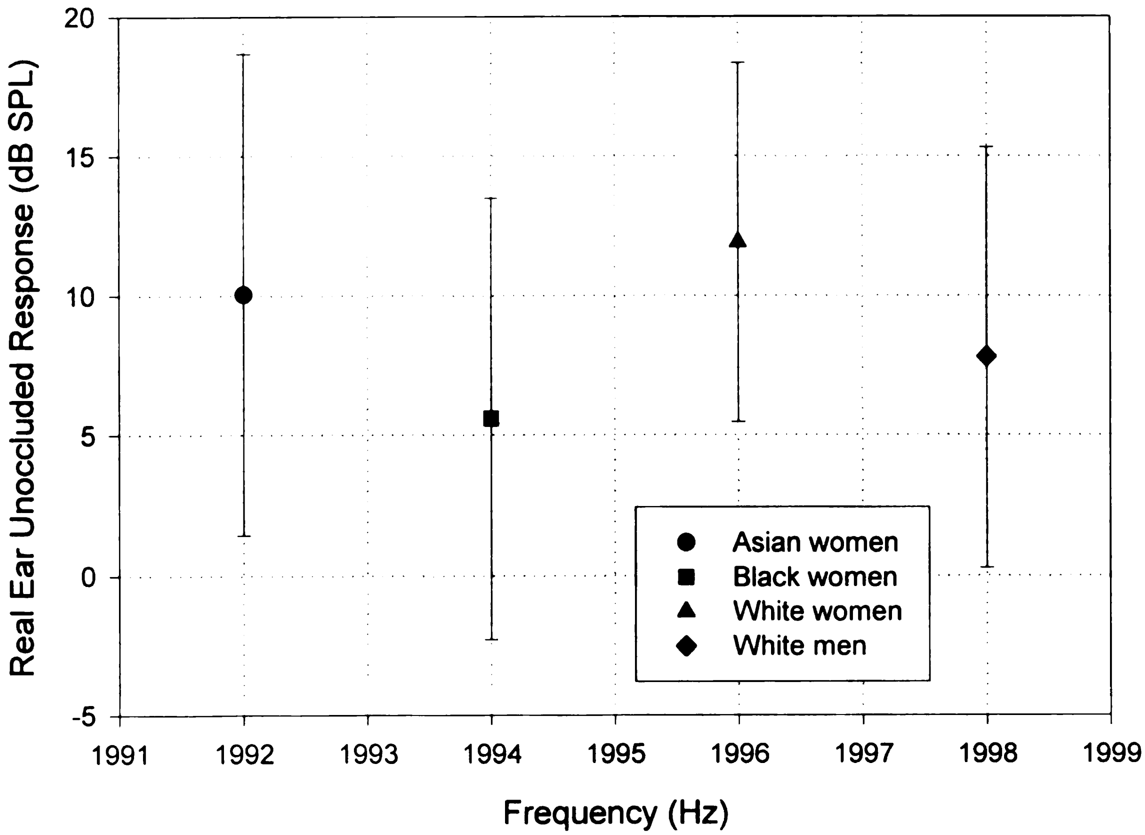

Figure 12. REUR response of all four groups at 8000 Hz, data points are offset for greater clarity.

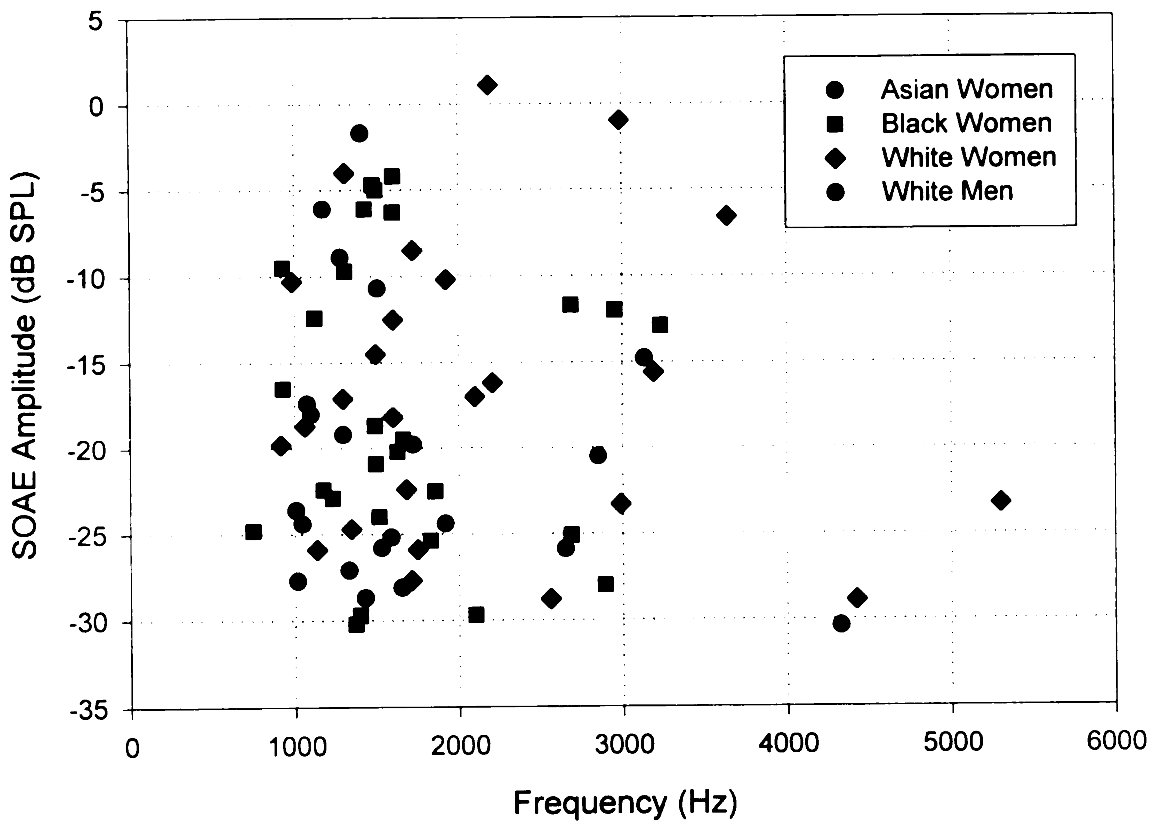

Figure 13. SOAE amplitude distribution across frequency among all groups.

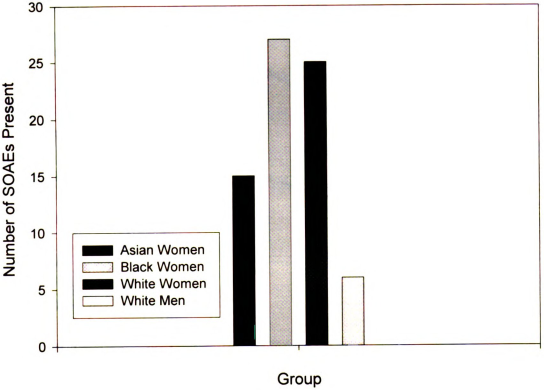

Figure 14. Number of SOAEs occurring among all groups.

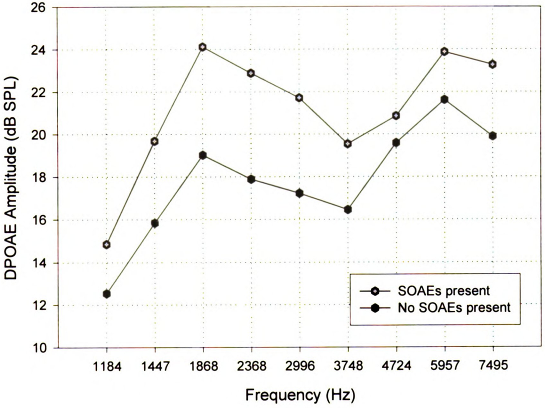

Figure 15. Comparison of DPOAE amplitude, including the noise floor, between persons that do or do not demonstrate SOAEs.

Normative Data

While it would not be prudent to over emphasize the overall normative data found in this study due sample size, a comment relating DPOAE results of college age women can be stated. Normative data that has been compiled by researchers has included both men and women. Gorga and colleagues (1997) included subjects within a wide age range (1.3-96.5 years) for their study. The data from the current study fall within the normative data compiled by other investigators (Gorga et al, 1997; Vinck et al, 1996). Figure 16 demonstrated the DPOAE amplitude across frequencies (+/- one standard deviation). The response amplitudes appear to be high, but this is not surprising. This study incorporated more women than men (30/40), and the previous data indicated that women have larger amplitude emissions than men. In addition, the ages of the women are within a more specific range, other researchers included individuals with a wider age.

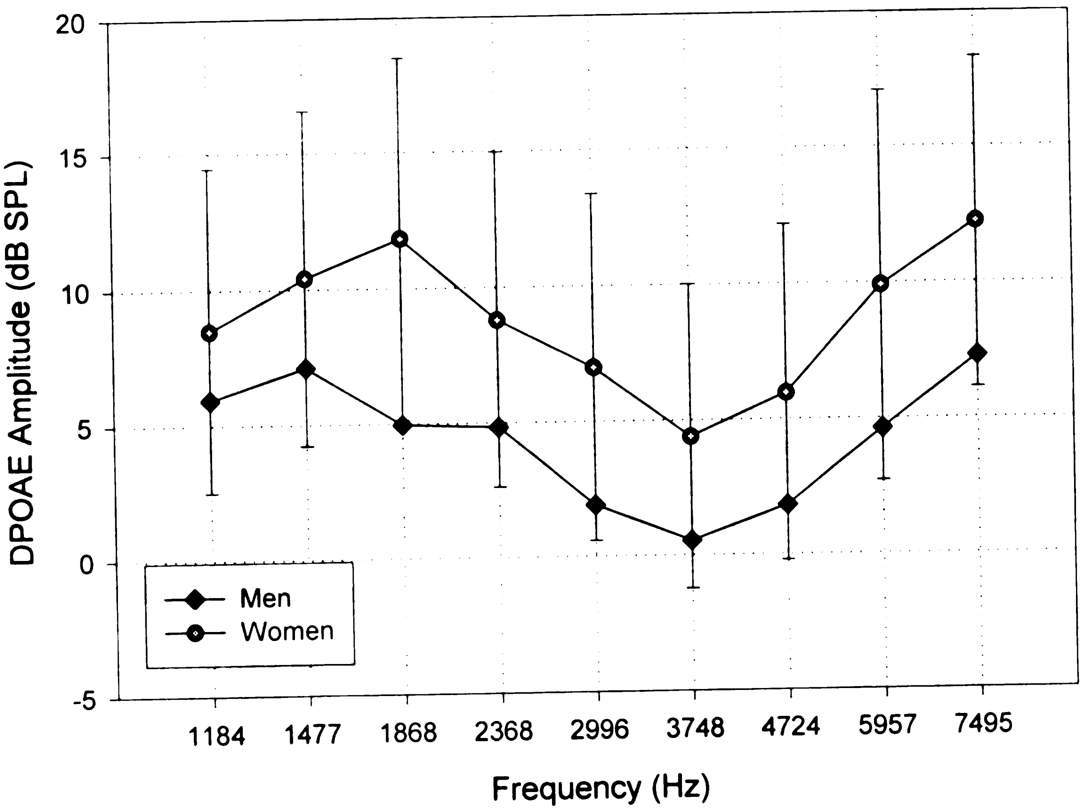

Figure 16. Normative DPOAE amplitudes across frequency for women with one standard deviation indicated.

CHAPTER V

DISCUSSION AND SUMMARY

Summary of the Study

The present study investigated the effects of racial and gender differences on DPOAE response amplitude. It was surmised that racial and gender differences might need to be accounted for when establishing normative data. Due to the differences in the shapes of the facial area among racial groups, it was believed that differences in ear canal resonance could contribute to differences in DPOAE responses (Hajniš, Farkas, Ngim, Lee and Venkatadri, 1994). Three racial groups were selected to take part in the study; Asian, Black and White individuals. These groups were chosen based upon prior research that indicated that racial and gender differences can be seen in SOAEs. Results reported in the literature indicated gender effects are present in the DPOAE amplitude. Thus far, explanations as to these differences have been speculative as to why these occur. In order to compare gender differences, White men were included as participants in the study.

Discussion of Relevant Findings

Data analysis of pure tone hearing thresholds found no significant differences among racial groups of women. Although these data are in contrast to what was found in prior research, it is not known if individuals in these studies demonstrated thresholds within normal limits as did the subjects in this current study (Post, 1964; Shepherd, Goldstein and Rosenblüt, 1964; Royster, Royster and Thomas, 1980). Post (1964) found that Blacks exhibited better overall thresholds than their white counterparts. Shepherd, Goldstein and Rosenblüt (1964) reported conflicting results. They found that White men and White women demonstrated better hearing thresholds than Black men and Black women. Royster, Royster and Thomas (1980) observed similar data of that of Post (1964), i.e., Black individuals demonstrated better hearing thresholds than White individuals. The results reported in the above studies were not an agreement with the results of the present study. This difference could be due to hearing losses found in the persons included in these prior studies, or to the differences between measurement techniques and equipment used. In addition, the small sample size that was used in the current study was smaller than any of the previous investigations. No racial differences were found in hearing thresholds for the current data.

Analysis of pure tone thresholds found statistically significant differences between gender at only one frequency (6000 Hz). One might assume noise exposure to be a factor between these two groups, however, all participants demonstrated hearing thresholds within normal limits. Most participants across all groups did indicate exposure to loud sounds at one time or another (e.g., at loud concerts). The results of the literature state that there is a gender effect among hearing thresholds across frequencies. Corso (1959) found that women have more sensitive hearing than men. Additionally, Royster, Royster and Thomas (1980) also found that women exhibited better thresholds than men. Again, these reports may be speculative in comparison to the current study due to technological advances and stricter guidelines established since these studies were performed.

In the present study, men exhibited a larger ear canal volume than women. This is consistent with previous findings (Zwislocki, 1970). Zwislocki stated that the average ear canal length is approximately 5% greater in men than women and the cross-sectional area is approximately 10% greater. Further, it has been documented that a gender effect related to ear canal volume is real (Margolis and Heller, 1987). White men have DPOAEs of lower amplitude than White women, and this could be due to the larger ear canal volume. While the DPOAE is of cochlear origin, ear canal volume by itself may interact with the amplitude of the DPOAE causing them to be significantly reduced in men. At the present time there is no information published in the literature relating ear canal volume to the gender effect seen in the present DPOAE amplitude.

There were no significant differences in the DPOAE amplitude among the racial groups of women. There were, however, significant gender effects, and these findings concur with the results in the literature. Gender differences in these data were seen at the frequency 4724 Hz. Even though a statistical difference was not documented at multiple frequencies, one can identify a definite difference of 2-7 dB between the DPOAE amplitude responses across all frequencies between men and women (see Figure7). There is still some discussion as to why gender effects occur. Hall, Baer, Chase and Schwaber (1994) attribute gender effects evident in DPOAEs to minor differences in detection threshold. While it could be argued that a decrease in hearing thresholds might contribute to differences in DPOAEs, this does not explain the DPOAE difference seen in these data, as there was only one frequency in the pure tone audiogram that was significantly different between genders. If this was indeed true, one would expect the DPOAE difference to occur in close proximity to the frequency where the hearing threshold differences occurred. Moulin et al. (1993) attribute gender effects evident in

TEOAEs and DPOAEs to a higher incidence of SOAEs in women (58%) than men (22%). Similarly, Bilger, Mathies, Hammel and DeMorst (1990) agree, stating that more women than men exhibit SOAEs, which can contribute to increased DPOAEs. A comparison of DPOAE amplitude was made between individuals who have SOAEs and those who did not exhibit such a response (see Figure15). These data support the notion that SOAEs do increase the DPOAE amplitude. The results of the present study indicated that women have more SOAEs than men. This was true among the racial groups tested, in that each female racial group demonstrated more SOAEs than the White men. It would be of interest to select men from the other corresponding racial groups to determine if this may be true for all racial groups. Perhaps the difference in DPOAE amplitude is due to the increased ear canal volume in men, which could decrease the amplitude of the emission before reaching the probe tip in the outer ear canal. Another plausible explanation to be considered is cochlear length of men is longer than in women that (Sato, Sando and Takahashi, 1991). These investigators suggested a dampening of the emission on outward propagation due to the longer outward travel time of the emission. However, this effect could be attributable to the combination of all of these factors that contribute to the difference in DPOAE amplitude observed in the present study. The overall gender effect found in the DPOAE amplitude data concur with Gaskill and Brown (1990) who found gender effects for the frequencies between 1000-5000 Hz, with DPOAE amplitudes being larger in women than in men.

Data analysis of real ear measurement found no statistically significant effects among racial groups of women. Since no racial effects were evident in the DPOAE data, no further analysis of ear canal resonance seemed warranted.

It has been shown that probe placement is crucial to accurate results with real ear measurement (Dirks, Ahlstrom and Eisenber, 1996; Shaw, 1974). In this study, the probe microphone was placed in each participant's ear at the mid-canal position. The probe microphone was inserted until the participant felt it was uncomfortable, typically the bony portion of the ear canal. The probe was then pulled out slightly for the participants' comfort and the REUR/REOR measurements were made. The results of these data are not likely to be relevant to the differences evident in the DPOAEs. If the differences in resonance were evident at higher frequencies, ear canal resonance may have an effect on DPOAE responses. If differences were seen at more than one frequency, between all groups, one would be more inclined to consider ear canal resonance characteristics to play a role in affecting DPOAE responses.

The present study did not find any racial differences s regards SOAEs. These findings do not agree with those of Whitehead et al. (1993) who did find a racial effect. Perhaps this could be attributed to a difference in subject populations. Whitehead et al. (1993) used both men and women of different racial groups, whereas this study included only women. In addition, they studied both ears of all subjects, while in the present study only one ear was tested.

Although the majority of SOAEs fell within the middle to lower frequency range (1000-2000 Hz) (see Figure 10), SOAEs do have an effect on DPOAE amplitude. While only one response out of all 73 SOAEs measured occurred at the same frequency as the DPOAE response, there appears to be an overall amplifying effect when SOAEs are present (see Figure 15). The perfect match between SOAEs and DPOAEs occurred at 1477 Hz at an amplitude of – 4.7 dB SPL. In order for the DPOAE to increase in amplitude, the SOAE has to occur at the same frequency or within close proximity to the response frequency, thus creating a superimposition of waves. This finding is consistent with that found by Bilger et al. (1990), Penner and Zhang (1997), and Whitehead et al. (1993). The overall SOAE records exhibited multiple responses at a variety of lower frequencies, rather than at the high frequencies. While it could be argued that the SOAE response seen here affect the DPOAE response, the frequencies at which the SOAEs occurred did not entirely match the DPOAE response frequencies. Yet, there is a definite indication that SOAEs tend to increase the DPOAE amplitude.

Whether the presence of SOAEs contribute to the increased DPOAE amplitude among the women is still speculative. Weir, Pasanen and McFadden (1988) state that SOAEs increase the amplitude of the DPOAE response when the frequencies are in close proximity. They found this difference to occur while using low levels of the evoking stimuli for the DPOAE. Weir et al. (1988) studied DPOAE using a growth function format, which measures the emission at different intensity levels at only one specific frequency. They stated that the SOAE has an effect on the DPOAE when they are within approximately 100 Hz of each other. This present investigation found fourteen SOAEs to be present within 100 Hz of the DPOAE response among all participants. This assumption could explain the gender effect demonstrated in the current data for the lower frequencies. While most women had multiple SOAEs, the majority of these SOAEs occurred at the mid-range of the spectrum (1000-2000 Hz), while the significant difference seen between men and women occurred at a higher frequency, there was an overall difference between genders. Of the 40 participants, 23 of whom demonstrated SOAEs, only one person had an exact frequency match between SOAE and DPOAE frequency. The DPOAE primary levels in this study were not similar, nor were the measuring conditions of the SOAE response, thus, these data cannot be readily compared to the results observed by Weir et al. (1988).

Conclusions

The development of otoacoustic emissions has greatly aided the audiologist's role in identifying site-of-lesions in persons with hearing loss. It is important to establish normative data on new equipment in order to compare data for accurate conclusions about possible pathology. This study examined the possible racial and gender effects on DPOAEs using normal hearing participants from a university population. The following questions were asked:

(1) Are there significant differences among DPOAEs recorded in different racial groups?

(2) Are there significant differences among DPOAEs recorded between gender?

The population used for the present investigation included men and women of a specific age group. Although no effects among the racial groups was evident in the DPOAE responses, this study confirmed that gender effects are important to consider and should be studied within a larger population. It has been suggested that gender effects can be accounted for by the noted difference in cochlear length, which may decrease the amplitude of an emission during outward propagation (Sato et al., 1991). Moreover, the gender effect may be influenced by increased ear canal volume seen between men and women. That is, the increase in ear canal size may have an effect on the recording of the OAE in the ear canal, thus, resulting in the gender differences that have been previously documented. The effect may also be influenced by the presence of SOAEs, which was observed in the current study. All of these factors, either single or in combination, may influence the amplitude of the DPOAE emissions between genders. Thus, gender differences need to be considered when establishing normative data for clinical use.

Implications for Further Research

The purpose of this study was to explore the effecst of race and gender on DPOAEs in order to establish normative data for clinical use. The present study used commercially available software and test equipment in order to elicit, record and measure otoacoustic emissions. In addition, all of the methods used in the present investigation included those used in routine clinical practice. Based on these findings, there are several suggestions for future research:

1) The sample population should include male participants of the several racial groups.

2) EOAE measurements of both ears of all participants should be included.

3) DPOAE measures should include DP-growth function measures at several intensity levels at a single frequency to more closely correlate those data to SOAE data.

4) Real ear measurements should employ a more accurate method for measurement of ear canal resonance in order to determine much smaller differences that may be present, since at this time one is unable to measure it accurately without causing physical stress to the participant.

5) Measurements of children similar to those used in the present study to identify a gender effect at younger ages and to establish clinical norms.

APPENDIX

Table 1. One-Way ANOVA of Hearing Thresholds (dB HL): All Groups.

Frequency (Hz)	df	F	P
250	3	1.82	0.161
500	3	1.19	0.328
1000	3	0.60	0.622
2000	3	0.45	0.720
3000	3	1.21	0.321
4000	3	2.80	0.053
6000	3	4.39	0.010**
8000	3	1.67	0.191

** $p<0.01$

Table 2. One-Way ANOVA of Ear Canal Volume (cm^3): All Groups.

Source	df	F	P
Group	3	10.82	0.000**

** $p<0.001$

Table 3. One-Way ANOVA of Height (in): All Groups.

Source	df	F	P
Group	3	29.27	0.000**

** $p<0.001$

Table 4. General Linear Model method of DPOAE Amplitude (dB SPL): All Groups.

Source	df	F	P
Group	3	3.835	0.018

* $p<0.05$

Table 5. One-Way ANOVA of Real Ear Unoccluded Response: By Frequency.

Frequency (Hz)	df	F	P
250	5	1.69	0.187
500	5	1.18	0.330
1000	5	0.69	0.562
2000	5	4.67	0.007*
4000	5	0.09	0.967
8000	5	1.27	0.298

* $p<0.01$

Table 6. One-Way ANOVA of the number of SOAEs.

Source	df	F	P
Group	3	2.54	0.072

Table 7. General Linear Model of DPOAEs with noise floor at 2 SD.

Source	df	F	P
Group	3	2.235	0.101

Table 8. General Linear Model of DPOAEs with and without SOAEs.

Source	df	F	P
Group	1	5.678	0.022

* $p<0.05$

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