EFFERENT AUDITORY PATHWAY AND LANGUAGE LEARNING

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Certificate

This is to certify that this dissertation entitled **“Efferent Auditory Pathway and Language Learning**” is a bonafide work in part fulfilment for the Degree of Master of Science (Audiology) of the student (Registration No. 16AUD024). This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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Declaration

This dissertation entitled "**Efferent Auditory Pathway and Language Learning**" is the result of my own study under the guidance of Dr. Ajith Kumar U, Professor in Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysuru (570006) and has not been submitted earlier in any other University for the award of any Diploma or Degree.

April, 2018 Registration No. **16AUD024**

Mysuru

Dedicated to

Dr. C. S. Vanaja

Who has made me the audiologist I am today;

To Ajith sir with heartfelt gratitude,

And to my dear Mumma and Dad.

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Abstract

The auditory efferent system is a complex pathway with to and fro innervations which aids in the fine-tuning of acoustic stimuli at multiple levels. The brainstem and associated nuclei play an important role in this process. The medial olivocochlear bundle of efferent auditory system is believed to aid speech understanding and learning through the inhibition of competing stimuli (efferent inhibition). The efferent system is believed to have a role in perceptual learning and appears to be flexible to short term auditory training.

This study was undertaken to assess the relationship between statistical language learning and the plasticity in the efferent system using an artificial language. Ninety participants participated in the study. They were divided into young, middle and elderly individuals based on their age. Their ability to acquire a novel artificial language using statistical probability cues was assessed. The functional strength of medial olivocochlear reflex was also studied using contralateral inhibition of otoacoustic emissions. Results showed that ability to use statistical probability to learn the new language reduced with increasing age suggesting that there is a role of both age-related decline cognition and working memory. However, no relationship was found between the language learning scores and efferent inhibition of OAEs. This suggest that caudal efferent system activity as assessed through contralateral inhibition of otoacoustic emissions may not modulate the higher-level language learning process. However, this requires further investigation using large cohort.

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Chapter I

Introduction

The auditory system is a complex pathway of to-and-fro innervations giving rise to complex interactions, affecting the encoding of acoustical stimuli from the cochlea till the auditory cortex. Processing occurs at each level of the auditory system to fine-tune the information reaching the cortex. The brainstem is known to play a substantial role in this process.

Ahissar and Hochstein, (2004) suggest that a top-down control mechanism enhances relevant information, which is especially important for listening and learning in adverse listening conditions. There are extensive corticofugal connections extending to the subcortical nuclei in the brainstem. The auditory efferent system originates in the auditory cortex and projects to the medial geniculate body (MGB), inferior colliculus (IC), cochlear nucleus (CN) and superior olivary complex (SOC) reaching the cochlea through olivocochlear (OC) fibers. Higher cortical centers communicate with the more caudal centers via multiple feedback loops, namely the (i) colliculo-thalamic-cortico-collicular; (ii) cortico-(collicular)-OC; and (iii) cortico-(collicular)-CN pathways (Terreros & Delano, 2015). The auditory efferent system consists of different brainstem nuclei, particularly the nuclei of the superior olivary complex. The superior olive emits fibers in two divisions namely the medial and the lateral superior olive via the olivocochlear bundle. Medial olivocochlear bundle (MOCB) innervates the outer hair cells in the cochlea whereas lateral olivocochlear bundle innervates the inner hair cells in the cochlea (Guinan, 2006). The corticofugal connections are known to reach the cochlear hair cells, via multiple efferent innervations. This efferent system serves multiple functions through interactions with the cortical centers. By the virtue of this complex encoding, listeners with unimpaired hearing can separate out a signal of interest from background noise, combine information from two ears, and localize sound sources with accuracy (Guinan, 2006; Irving, Moore, Liberman, & Sumner, 2011). The extent of these interactions is yet to be fully comprehended.

The MOCB is the most studied among the olivocochlear bundles (Ciuman, 2010). The MOCB can be studied noninvasively through the measurement of otoacoustic emissions (OAES), and the influence of noise on the same (Kemp, 1979; Zhao & Dhar, 2011) . The amplitude of evoked otoacoustic emission responses of subjects have been found to be reduced in response to presence of simultaneous noise (Collet et al., 1994)**.** This is an indicative of the inhibition mechanism operating at the level of the brainstem nuclei, which modify the mechanoelectrical properties of the outer hair cells. This has direct implications in speech-in-noise processing affecting auditory processing of complex speech signals. Reduced suppressive effect of contralateral noise has been found in children with learning disabilities, as well as those having lower scores on behavioral tests of (central) auditory processing (Burguetti & Carvallo, 2008).

Kumar, Hegde and Mayaleela (2010) hypothesized that corticofugal pathways may play an important role in fine-tuning the communication between the brainstem and the cochlea, making these structures more sensitive to subtle changes in acoustic stimuli. They reported that contralateral inhibition of distortion product otoacoustic emissions had significant relationship with the perceptual learning of non-native speech sound discrimination in adults. De Boer and Thornton, (2008) suggest that the MOCB mediates learning strategies that facilitates speech in noise perception. It was found that MOCB activity could serve as a predictor for improvement in auditory learning. Also, significant improvement in performance after auditory training positively correlated with increased activation of the MOCB. The OCB was found to be malleable to training presumably due to task-related adaptation of the cortical efferents. Thus, descending feedback pathways have been established to play an important role in both short-term and long-term plasticity (Jessica de Boer & Thornton, 2008), consequently having an effect on learning.

In order to correlate the effects of plasticity on auditory learning it is necessary to study real-time learning of languages without the effect of previous exposure. Implicit or incidental language learning is one method of examining real-time learning. Statistical language learning or incidental language learning has been studied in order to better describe the process by which infants acquire language. In this paradigm, infants are exposed to short durations of training stimuli consisting of the artificial language streams (word strings or grammar) and responses to test stimuli are obtained in the form of physical or physiological changes in activity of the infant. In this learning mechanism, the subjects use statistical probability cues to acquire the rules of a new language or an artificial language (Dienes, 1978; Gomez, Gerken& Schvaneveldt, 2000).

Studies by Saffran and colleagues have investigated the effect of incidental language learning in adults using a variety of stimulus such as word strings, sentence strings as well as tone sequences. It has been established that adults are capable of abstracting new conditional probabilities from only a few minutes of exposure based on the probability of occurrence of adjacent segments; however differences exist in the learning of statistical language in infants and adults (Jenny R. Saffran, Newport, &

Aslin, 1996; Jenny R. Saffran & Saffran, 2003). Mirman et.al. compared the statistical segmentation and word learning in infants and adults (Mirman, Magnuson, Estes, & Dixon, 2009). The authors observed a difference in the dynamics of incidental language learning across infants and adults which was attributed to the linguistic exposure, presence of a larger vocabulary, and phonotactic experience. However, these effects have not been investigated as an effect of age.

Need for the study

Studies by Reber (1969), Aslin, Saffran and Newport (1996), and Gomez and Gerken (2000) have established the ability of adults and children to acquire artificial language based on transitional cues. In the absence of previous exposure to the given language, prosodic cues or presence of distinct word boundaries participants are capable of learning a novel grammar structure and also familiarization with a new vocabulary. However, there is dearth of literature regarding statistical language learning in speakers of Indian languages.

Efficiency of perceptual learning is dependent upon the top-down processing of information in the central auditory nervous system (CANS) (Banai & Ahissar, 2009). Hence, we seek evidence of plasticity in the adult auditory efferent system, specifically the olivocochlear bundles which could potentially facilitate language learning. Recent finding indicate that the efferent auditory system may also show indications of plasticity, being affected by auditory training (Jessica de Boer & Thornton, 2008). The efferent system can easily be evaluated through the non-invasive procedure of contralateral inhibition of otoacoustic emissions (CITEOAE), particularly using transient stimulus.

CITEOAE has been found to be reduced in children with language difficulties as well as older adults having deterioration of auditory processing abilities with age (Carolina Abdala, Dhar, Ahmadi, & Luo, 2014; Sanches & Carvallo, 2006).

However, it remains to be seen if efferent inhibition can be directly correlated with language acquisition capability. There is need for literature regarding the changes in efferent plasticity due to aging, as well as its influence on incidental language learning.

Aim of the study

To determine whether efficiency of language learning shows a correlation with auditory efferent functioning.

Objectives of the study

- To compare the learning efficiency of an artificial language across age groups through artificial language using statistical language learning paradigm.
- To compare the contralateral inhibition of TEOAEs across age groups
- To correlate learning efficiency measures with the contralateral inhibition of TEAOEs

Hypothesis of the study

- There is no significant effect of age on language learning efficiency
- There is no significant effect of age on contralateral inhibition of TEOAEs
- There is no significant relationship between language learning ability and efferent inhibition.

Chapter 2

Review of literature

2.1 The auditory efferent system:

2.1.1 Introduction. The auditory efferent system is a complex connection of neural pathways extending from the auditory cortex to the brainstem nuclei, finally terminating at the cochlear hair cells. The brainstem nuclei play as essential role in modulating the input passing to the cochlea (Delano & Elgoyhen, 2016; Guinan, 2006). A salient component of the auditory efferent system is the superior olivary complex. The superior olivary complex projects into olivocochlear bundles which bifurcate into two components, namely the medial and lateral olivocochlear bundles (Rasmussen, 1946).

The MOC is known to have inhib0itory effects on the gain provided by the cochlear amplifier (Kemp, 2002; Probst, Lonsbury-Martin, & Martin, 1999). MOC efferents originate from larger neurons with myelinated axons and terminate directly on OHCs and on radial auditory nerve fibers beneath inner hair cells (lHCs). LOC fibers innervate auditory nerve fibers and thus are in a position to change the firing of auditory nerve fibers. Thus, the CNS is capable of influencing the operation at the level of the cochlea.

2.1.2 Otoacoustic emissions. Otoacoustic emissions (OAEs) are sounds of cochlear origin which arise in the ear canal due to backward transmissions of sound from the cochlea, and can be recorded non-invasively by a microphone placed in the ear canal (Guinan, 1996; Kemp, 1986). OAEs are believed to occur as a by-product of a unique mechanism known as the ‘cochlear amplifier’. The cochlear amplifier is a result of nonlinear electromechanical distortion which enhances the traveling wave to give rise to mechanical energy which travels outward via the middle ear (Kemp, 2002; Shera & Guinan, 1998).

2.1.3 OAE evoked by transient stimuli. OAEs have been recorded due to spontaneous activity (spontaneous OAE) as well as a response to stimuli. According to the stimuli used, and method of acquisition, OAEs may be classified as distortion product otoacoustic emissions (DPOAE), stimulus frequency otoacoustic emissions (SFOAE) and transient evoked otoacoustic emissions (TEOAE). Each of these measurements have been evaluated on human subjects and compared for utility (Shera & Guinan, 1999; Zurek, 1985).

Keppler et al., (2010)examined the test-retest reliability and replicability of TEOAE and DPOAE measurements in 56 normal hearing individuals over a period of one week. It was observed that both measures have low intrinsic variability, provided noise sources are controlled during testing. However, the results indicated a higher reliability of TEOAEs than DPOAEs at similar half-octave band frequencies.Stuart and Cobb, (2015) examined the test-retest reliability of TEOAE measurements in 28 young adults with normal hearing sensitivity. The authors did not find statistical significance between TEOAE measurements across tests repeated over a period of 1-2 days post initial testing. They concluded that TEOAE measurement is reliable from test to test and can be used as a suitable tool to monitor the MOC reflex status over time.

2.1.4 Efferent inhibition of TEOAE. The MOC is known to have inhibitory effects on the gain provided by the cochlear amplifier in the presence of noise (Kemp, 2002; Probst et al., 1999). These effects have been studied for both ipsilateral and contralateral noise stimulation (Berlin, Hood, Hurley, & Wen, 1994; Giraud, Collet, Chéry-Croze, Magnan, & Chays, 1995; Shera & Guinan, 1999). However, effects of temporal masking play a role in measurement of ipsilateral inhibition (Tavartkiladze, Frolenkov, Kruglov, & Artamasov, 1994).

In a study by Stuart and Cobb (2015) TEOAE was recorded using 60 dB peSPL linear click stimuli with and without a contralateral 65 dB SPL broadband noise suppressor. A TEOAE was considered present if the emission was 6 dB or more above the noise floor. Efferent inhibition was calculated by subtracting TEOAE amplitude in noise from the measurement in quiet. Good reproducibility and stimulus stability was obtained over a period of 2-3 days, leading to the conclusion that contralateral inhibition of TEOAE has a good test-retest reliability (Stuart & Cobb, 2015). These results have been found to be comparable to other studies on validity measures of CITEOAE (Gargeshwari & Kumar, 2016; Mishra & Lutman, 2013).

2.1.5 Subjective factors affecting contralateral inhibition of TEOAE.

2.1.5.1 Age. Age is considered to be an important factor affecting the amplitude of inhibition of TEOAEs(Abdala, 1998; Abdala & Chatterjee, 2003; Parthasarathy, 2001; Quaranta, Debole, &Di Girolamo, 2001; Yılmaz, Sennaroğlu, Sennaroğlu, & Köse, 2007). With increase in age, the auditory nervous system deteriorates, having an effect on all subsystems (Gordon-Salant, 1998). Parthasarathy (2001) studied the effects of age on TEOAE inhibition amplitude in the age range of 20 to 79 years and found interactive effects of age and inhibition amplitude. This variation was influenced by stimulus intensity as well as intensity of the competing acoustic stimuli (noise). The results of this study show that mean CITEOAE amplitude showed minor variation across the age groups up to 60 years of age, followed by a sharp decline from 60-79 years of age. This observation could be attributed to age related changes in audibility, cochlear tuning as well as decrease in neural transmission efficiency in older individuals, especially above 60 years of age.

Kim and Frisina (2002) have concluded that the MOC efferent system can be characterized as a nonlinear adaptive filter activated during speech processing in background noise and also as a cocktail party processor. Also declines in MOCB function show corresponding declines in speech understanding in noise (Kim & Frisina, 2002). Changes due to aging can be reflected in changes in the amount of inhibitory input passed to the cochlea in the presence of noise at the neural level. As efferent inhibition has been linked to better speech understanding in noise, this phenomenon provides and explanation for difficulty during hearing in noise commonly experienced by elderly individuals (Burguetti & Carvallo, 2008; Smith, Turner, & Henson, 2000; Yilmaz et al., 2007).

A study by Quaranta and colleagues examined the relation between TEOAE, audibility and age. It was found that there is no age effect on TEOAE inhibition in the subjects aged 20 to 78 years (Quaranta et al., 2001). Thus, contradictory results have been found in relation to the aging effects of MOC inhibition.

2.1.5.2 Effect of attention. Attention, a higher order cognitive process is also observed to have an effect on the peripheral systems. Froelich and colleagues investigated the effect of selective attention on the MOC function and found that found that TEOAE amplitude decreased during visual and auditory attention for all 13 subjects tested (Froehlich, Collet, & Morgon, 1993). Thus, they concluded that selective attention modifies cochlear micromechanical properties. Attention has an effect on physiological processes in the cochlea thereby resulting in reduced inhibition effect on the cochlear amplifier. This was attributed to the existence of a top-down control mechanism that influences the peripheral effects through centrifugal connections Giard, Collet, Bouchet, & Pernier, 1994). Effects of attention need to be controlled in the testing of contralateral inhibition of OAE (Giard et al., 1994; Meric & Collet, 1992, 1994).

2.1.5.3 Right ear advantage. Kei and colleagues investigated ear asymmetries in TEOAE recording in children and found that the right ear values presented with higher values in 'reproducibility' and 'response level' than the left ear (Kei, McPherson, Smyth, Latham, & Loscher, 1997). A significant difference in SNR across activity states was also evident. Another study revealed that higher otoacoustic emission amplitudes were found for the right ear compared to the left ear, which is consistent with the right-ear dominance normally seen in young adults (Tadros et al., 2005). However, this right ear advantage reduced with age. Similar results have been found with prominent right ear advantage evident in infants, younger children and young adults (Aidan, Lestang, And, & Bonfils, 1997; Berninger, 2007; Driscoll, Kei, & McPherson, 2000; Pavlovčinová et al., 2009)

2.2 Efferent Plasticity and perceptual learning.

Neuroplasticity is the ability of the brain to change throughout life. This phenomenon has been the subject of research for decades. Early studies by Krishnan and colleagues demonstrate that language experience affects brainstem activity. The authors observed speakers of tonal languages have enhanced frequency following responses

(Krishnan, Xu, Gandour, & Cariani, 2005). Kumar, Hegde and Mayaleela (2010) observed that adults are capable of differentiating non-native phonetic contrasts through perceptual learning, in spite of previous exposure to language specific phonetic patterns. In the study it was found that quick learners of non-native speech sounds showed greater amplitudes of MOC inhibition. It can be concluded that complex feedback circuits modulate input to the brainstem and cochlea in order to aid the process of perceptual learning.

Multiple studies have found strong relationships between brainstem plasticity and long term auditory training with music as well as linguistic stimuli (Parbery-Clark, Strait, Hittner, & Kraus, 2013; Parbery-Clark, Anderson, & Kraus, 2013; Strait, Parbery-Clark, Hittner, & Kraus, 2012). Longitudinal music training has been observed to mitigate the effects of aging such as loss of timing cues, loss of spectral fine-tuning etc. Thus, the amount of reduction in stimulus response latency at the level of brainstem and cortex with age is lower in trained musicians (Kraus et al., 2014; Strait & Kraus, 2014). These studies provide a window to the exploration of minor neural changes owing to CANS plasticity. While these represent life long auditory experiences, it is found that brainstem processing can also be modified by shorter-term auditory training (de Boer & Thornton, 2008; Song, Skoe, Banai, & Kraus, 2012).

The mechanism of perceptual learning is believed to be mediated by a cascade of mechanisms involved in top-down processes (e.g., attention, language, and memory) as is explained by the Reverse Hierarchy Theory (RHT) (Merav Ahissar & Hochstein, 2004). The RHT states a dislocation between bottom-up processing and top-down perception of information. According to the RHT there is a gap between local encoding at the level of peripheral sense organ and global processing at the CANS. Local levels selectively encode fine spectro-temporal acoustic features; while higher levels form broader, abstract categories by integrating spectro-temporal information. Feedback and feed-forward loops exist which exert control over the local to global transfer. However, Local-to-global transfer would only occur following substantial training (Ahissar, Nahum, Nelken, & Hochstein, 2009).

Ahissar and colleagues have described the “Eureka effect” which suggests that, single exposures (priming) can induce strong and long-lasting effects that clearly change our perception. This mechanism is governed by a top-down control mechanism (Ahissar & Hochstein, 2004). This theory is supported by evidence of top-down corticofugal enhancement at the level of the brainstem nuclei (Suga, Xiao, Ma, & Ji, 2002). The RHT has implications in various studies of short term perceptual training (de Boer & Thornton, 2008; Kumar et al., 2010). There is also evidence of improved prognosis of auditory learning in children with dyslexia and/or learning disabilities (Banai & Ahissar, 2009). Banai and Ahissar (2009) described the implication of RHT in auditory learning of tones as well as complex stimuli and its relation to working memory in individuals with learning difficulties using a short duration training paradigm. Thus, this top-down learning mechanism can provide a basis for incidental language learning mechanisms and associated physiological changes at the brainstem level.

2.3 Statistical language learning.

2.3.1 Theoretical basis. Pothos, (2007) presented a theoretical review of the mechanisms of artificial language learning. Through a review of over a hundred studies, the author aimed at defining the processes involved in artificial grammar learning (AGL). He described two terms – implicit and explicit learning which together contribute to performance on AGL. Implicit learning is that knowledge which is not consciously activated at the time of a cognitive operation. This process could be concurrently activated with other cognitive operations and working memory. Explicit learning involves adopting a frequency-independent rule of language according to specific similarity. It also involves associative learning with the aid of co-occurrence knowledge. The acquisition of AGL involves specific theories of learning. These can be attributed to competence in aspects such as *rules, similarity,* and *associative learning* (Pothos, 2007).

Learning of an artificial grammatic stream was first studied by Reber in 1967. Reber (1993) considered implicit learning as that which occurs independently of an intention or effort to learn or the actual process of learning, and as occurring independently of the products of learning. Implicit cognition typically involves processes that are automatic, nondirected, nonintentional, and sensitive to multiple regularities, whereas explicit cognition involves processes that are flexible, controlled, and directed (Reber, 1993) In the study the author generated a finite state grammar pattern which has a specific starting and ending point with rule-based transition. Sequences are generated from finite state grammar. The language thus formed divides the sequences into two – *grammatical* and *ungrammatical*. Grammatical sequences are those which follow the sequence and rules of the grammar; while ungrammatical ones are those which violate it. In the process of testing the acquisition of this new language training periods are provided preceding the test. Also, training stimuli differ from the test. These paradigms have been used in various studies (Dienes, 1978; Rebecca L. Gomez, Gerken, & Schvaneveldt, 2000; Pothos, 2007; Romberg & Saffran, 2013).

Another method of studying language acquisition using implicit learning is word segmentation tasks (Newport & Aslin, 2004; Jenny R. Saffran & Saffran, 2003). These authors interpret that infants are able to use the distributional properties of adjacent segments in an uninterrupted stream of syllables to extract statistical coherence of samples drawn from that corpus. This occurs on the basis of the probability of occurrence of the segments in a sequence. For example, the probability of occurrence of the combination *par-ty* (in the word 'party') is more than the combination *par-ba* which is registered as a non-word in the users lexicon (Jenny R. Saffran, Johnson, Aslin, & Newport, 1999). This probability of occurrence is termed as 'transitional probability'. It has been observed that adults as well as infants are capable of extracting word versus non-word information based solely on the transitional probability of adjacent segments (Newport & Aslin, 2004).

2.3.2 Previous studies in AGL. Behavioral as well as evoked potential studies have been performed to assess the ability of individuals to acquire statistical language. Gomez and colleagues used a finite state grammar to study how 8-month-old infants perform on AGL with brief exposure period ranging from 50 to 130 seconds. The authors have found that infants are able to achieve above chance level scores. Also, they are capable of generalization and transfer of newly acquired skills across a new grammatical string as well as across new vocabulary (Gomez & Gerken, 1999).

Saffran and colleagues used word segmentation tasks to study the effect of brief exposures on incidental language learning in adults and children. It was found that infants as well as adults are capable of extracting probabilistic information in series of speech segments without word boundaries (Saffran et al., 1999). There is a corpus of behavioral studies that have used stimuli such as sentence strings, word strings as well as tone sequences to compare the computation of transitional probability cues by different populations (Mandikal Vasuki, Sharma, Demuth, & Arciuli, 2016; J R Saffran, Johnson, Aslin, & Newport, 1999). Populations studied include infants, adults, musicians versus non-musicians, as well as individuals with Alzheimer's and Parkinson's disease (Pothos, 2007).

To illustrate the neurobiological substrates of implicit language learning, authors have carried out measurements using event related potentials. It was found using evoked potential studies that 8 month old neonates are able to extract statistical properties of the speech input with which they can detect the word boundaries in a continuous stream of syllables without any other morpho-syntactic cues (Teinonen, Fellman, Näätänen, Alku, & Huotilainen, 2009). The mechanism of language learning has been observed to be diffused across large areas of the cortex as well as subcortical areas. Neuroimaging studies have highlighted the importance of the prefrontal cortex, in learning, memory, and language processing (Scharf, Magnan, Collet, Ulmer, & Chays, 1994). In this study fMRI was carried out to visualize interaction at the level of the hippocampus by assessing learning-related changes during artificial language acquisition. Authors found that an increase in proficiency level of the artificial language corresponds to decreased left hippocampal activity. It also involves recruitment of the left inferior frontal gyrus (Broca's area), which is known to be a region that contributes to syntax processing. Learning related changes have thus been observed in middle temporal lobes and left prefrontal cortex as a consequence of artificial language learning. A study by Abla (2008) utilizes event related potentials, namely N400 and P2 components of auditory evoked potentials to delineate the activation patterns incited by implicit learning of word segmentation. They have also divided their population in a hierarchy comprising of low, middle and high learners based on behavioral and electrophysiological results. Increased activation was found in the parieto-frontal areas of the cortex which corresponded to ability to learn novel probabilistic information (Abla, Katahira, & Okanoya, 2008).

2.4 Working memory and language learning.

The work of Baddeley and colleagues have established the crucial role of working memory in language learning through studies on language acquisition in various populations. The model of working memory by Baddeley delineates the subsystems of working memory which include the phonological loop, the visuospatial sketchpad, the central executive, and a fourth subsystem, the episodic buffer. Each subsystem has a role to play in the storage, retrieval and utilization of learned linguistic information (Baddeley, 2003).

The authors have discussed the implication of the phonological loop during native language learning (Baddeley, Papagno, & Vallar, 1988). The study of patients with aphasia and similar cortical lesions have shown phonological loop deficits (Vallar, Corno, & Basso, 1992). Thus, the neurobiological correlates of working memory translate to language mechanisms. Banai and Ahissar have explored the role of perceptual learning in improving working memory in children with learning disabilities using simple and complex tones. It was found that training on auditory stimuli in learning tasks corresponds to improvement in working memory (Banai & Ahissar, 2009). Thus, working memory has direct implication on language.

Chapter 3

METHOD

3.1 Participants

A total of 90 participants with normal hearing sensitivity were included in the study. The participants were duly oriented to the procedures of testing and written informed consent was obtained from each of the participants (Venkatesan, 2009). The participants were divided into three groups based on their age. Participants in the age range of 20 to 30 years comprised the young normal hearing adults (YNH) group; participants in the age range of 31-50 years constituted the middle aged normal hearing adults (MNH); and participants in the age range of 50-70 years constituted elderly normal hearing group (ENH). Table 3.1 shows the distribution of the sample according to age and gender.

Table 3.1.

Demographic details of the participants

Group	No. of subjects	Mean age (years)	Number of males	Number of females
YNH 18 – 26	40	22.10 SD = 2.384	6	34
MNH 30 to 48	20	35.15 SD = 5.833	13	7
ENH 50 to 61	30	53.13 SD = 3.203	13	17

3.2 Inclusion criteria and exclusion criteria

All participants had

- pure tone air conduction hearing thresholds within 15 dBHL at octave frequencies from 250 Hz to 8000 Hz. Participants of the ENH group had pure tone air conduction hearing thresholds within 25 dBHL at higher frequencies (4kHz and 8kHz)
- normal middle ear functioning, evident through ‘A’ type tympanogram (Jerger, 1970) with both ipsilateral and contralateral acoustic reflexes present within normal limits (Ha A& Jiong H, 2017; Gupta & Vanaja, 2016)
- speech identification scores >80% at 40dB SL (with reference to speech recognition threshold) measured using standardized phonetically balanced word lists in the participants’ native language

- measurable transient evoked otoacoustic emissions (TEOAEs) for 60 dBSPL clicks with a SNR of 6dB
- normal speech and language, with no history of language, cognitive or neurological deficits
- no exposure to loud noise or use of ototoxic drugs as ascertained through a structured interview
- Formal education at least up to 10thstandard

3.3 Test environment

Pure tone audiometry, immittance evaluation and OAE testing was carried out in a well-lit, sound treated room having noise levels within permissible limits (ASHA, 2005) All other testing, namely statistical language learning evaluation was carried out in a quiet, well lit room with adequate ventilation and no distractions.

3.4 Instrumentation

Calibrated two channel MA3 diagnostic audiometer (MAICO diagnostics GmbH, Berlin) with TDH 39 supra-aural headphones was used for threshold estimation and speech audiometry. Calibrated GSI TYMPSTAR immitance meter (Grason-Stadler, Minneapolis, USA) was used for tympanometry and acoustic reflex testing. A calibrated otoacoustic emissions analyzer – Otodynamics ILO V6 (Otodynamics, Hatfield, Hertforshire UK) with Etymotic ER 10C probe was used for measurement of OAEs.

An HP Pavilion core i5 Laptop was used for stimulus presentation and response acquisition of incidental language learning. The laptop was equipped with Adobe Audition CS5, Windows Media Player, and DMDX(Forster, 2003) softwares for stimulus recording, presentation and response acquisition respectively. The stimulus was presented binaurally through calibrated Sennheiser HD 380 Pro supra-aural headphones.

3.5 Stimuli

Efficiency of learning of an artificial language was tested using 2 types of synthetic speech material; namely, synthetic word strings and synthetic sentence strings.

3.5.1 Synthetic word strings. An artificial language learning task, adapted from Newport and Aslin (2004) was used to investigate the subjects' ability to utilize transitional probability cues for discrimination of word boundary. Eight consonants (/p/, /t/, /k/, /b/, /d/, /g/, /r/, /l/,) combined with five vowels (/a/, /i/, /o/, /u/, /e/) were used to form 14 different consonant vowel (CV) syllables, further combined to form 20 trisyllabic words (Newport & Aslin, 2004). The syllables were recorded by an adult female speaker using a laptop connected to Motu (Motu, Cambridge, Massachusetts) external sound card and a dual diaphragm studio condenser microphone (Behringer, Willich, Germany) loaded with Adobe Audition (2015) software in a sound treated room. Out of the 14 syllables, 10 were placed in the first and last position in 5 trisyllablic word frames, while the remaining 4 syllables formed the central portion, i.e. the 2nd syllable. Thus, a list of 20 trisyllabic words was formed. The trisyllabic words enlisted above formed the 'true word' vocabulary; whereas, any other combination of syllables would form a 'non-word'. For example, 'badite'. 'ketodu', 'pikura' are defined as 'true words', while 'doguku', 'kudogu', 'doguto' are 'non-words' as shown in table 3.2.

Table 3.2.

Design of the trisyllabic words used in synthetic vocabulary task

1st–3rd Syllable (frames)	2nd Syllables	Words	
ba_te	Di	badite	pitora
gu_do	ku	bakute	pipara
pi_ra	to	batote	kedidu
ke_du	pa	bapate	kekudu
lo_ki		gudido	ketodu
		gukudo	kepadu
		gutodo	lodiki
		gupado	lokuki
		pidira	lotoki
		pikura	lopaki

An artificial language generator software was custom designed at the institute to generate a string of trisyllablic words using the above-mentioned CV combinations. The CV combinations were concatenated together to form the stimulus string which consisted of trisyllabic "words" and "non-words". The occurrence of words and non-words were randomized within the training stimulus such that the transitional probability of syllables within a word will be 1 for true words; and 0 for non-words. Transitional probability is calculated as:

$$\text{Transitional probability of } Y \mid X = (\text{Frequency of } XY) / (\text{frequency of } X)$$

The resulting string was analyzed and processed further to eliminate unwanted clicks, noise or silence gaps. No discernible word boundaries were present in the training stimulus string. The stimulus was calibrated using a sound level meter attached to Kemar manikin. The sound file thus created was looped to provide an auditory training period of 10 minutes duration. Trisyllabic words were spliced from the original sound file to be presented as test material via DmDx software.

3.5.2 Synthetic sentences. Grammatical strings were generated by traversing through the links in a finite state grammar pattern adapted from (Gomez & Gerken, 1999) as shown in figure 3.1. The vocabulary was replaced by bisyllabic words with CVCV pattern to suit the phonological pattern observed in Indian languages. A sentence is defined as ‘grammatical’ if it follows the pattern of the finite state grammar, and ‘ungrammatical’ if the order of words in the sentence is randomized.

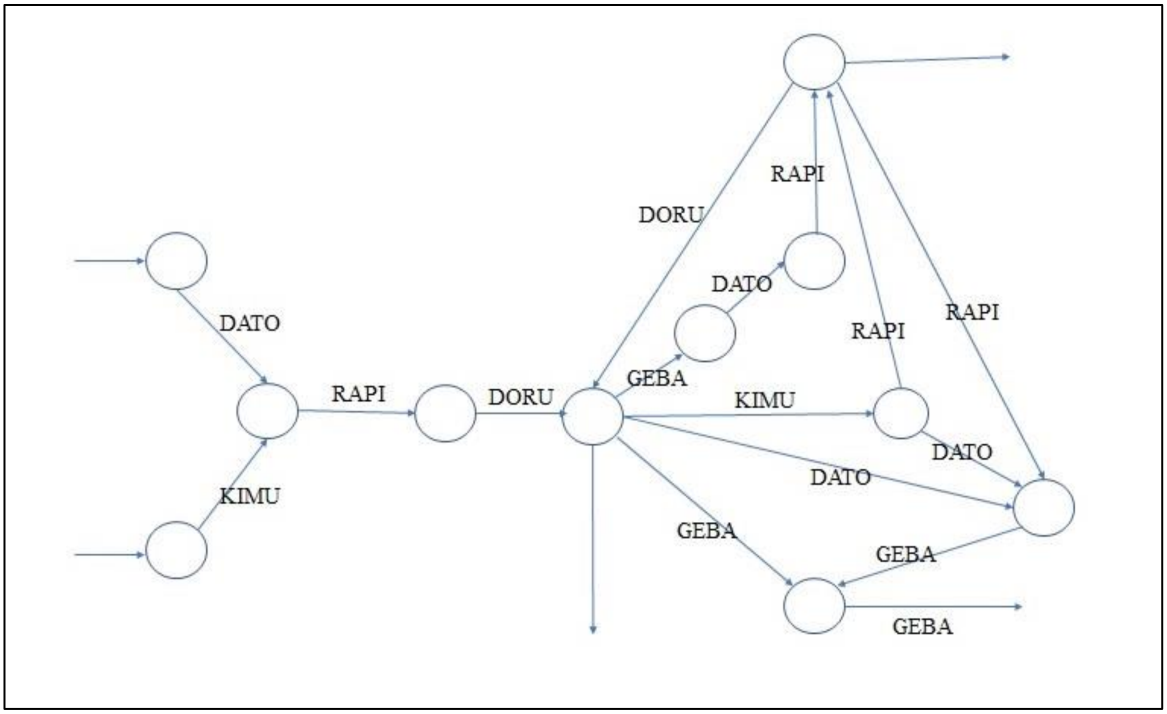

Figure 3.1. Pattern of artificial grammar (adapted from Gomez & Gerken, 1999). The arrows indicate the word order to be followed in between positions denoted by circular points

Swapping the first and the last words of a grammatical string can generate ungrammatical strings. For instance, the grammatical string ‘KIMU RAPI DORU DATO’ can be made ungrammatical by swapping DORU AND KIMU, resulting in DORU RAPI KIMU DATO. Table__ shows examples of some of the grammatical strings that could be generated with the Figure __. 15 grammatical strings generated using the finite state were as training stimuli. 10 new grammatical and ungrammatical strings were generated for use during the test phase such that the items used in the training stimuli differed from the test.

Table 3.3.

Examples of grammatical and ungrammatical sentence strings prepared using the grammatical structure from figure 3.1.

Grammatical sentence string	Ungrammatical sentence string
DATO RAPI DORU	RAPI RAPI DORU DATO
DATO RAPI DORU DATO RAPI	GEBA KIMU DATO
KIMU RAPI DORU KIMU DATO	KIMU DATO RAPI DATO
KIMU RAPI DORU GEBA GEBA	RAPI GEBA KIMU KIMU
KIMU RAPI DORU DATO RAPI DORU	GEBA GEBA RAPI DORU KIMU

Sentence strings were recorded by an adult female speaker in a sound treated room using a condenser microphone connected to a Motu external sound card done using a laptop loaded with Adobe Audition CS5 software at 44100 sampling frequency. The recordings were analyzed and processed further to eliminate unwanted clicks, noise or silence gaps.

3.6 Procedure

The testing procedure was explained to the participants and informed consent was taken. Verbal interview was carried out to ensure that the participant had no relevant otological or neurological abnormality. Initial hearing screening was performed to ensure normal hearing sensitivity and middle ear functions, as well as presence of TEOAEs.

3.6.1 Recording of OAEs. The subjects were made to sit in a well-lit, sound treated room. TEOAEs were recorded using Otometrics ILO V6 software. TEOAE measurement was carried out in the right ear in two conditions- quiet and noise. Precautions were taken such that the probe placement remained unaltered during both the conditions. OAEs were recorded for linear clicks in quiet at 65 dB SPL. In the second condition (in noise), continuous white noise at 60 dB SPL was presented to the contralateral ear through the insert ER-3A receiver (Etymotic Research Inc., Elk Grove Village, IL) from a calibrated MAICO MA3 audiometer. The difference in the amplitude of TEOAEs of both conditions [TEOAE amplitude in quiet (average of two recordings) – TEOAE amplitude in the presence of contralateral noise (average of two recordings)] was considered for analysis as the magnitude of contralateral inhibition.

3.6.2 Statistical language learning. Participants were made to sit comfortably in a quiet and well illuminated room. During the training phase participants were made to listen to the word strings or the grammatical sentence strings respectively through a headphone. Stimuli was presented at 70 dBSPL. The total duration of training was 10 minutes each, amounting to a total of 20 minutes. During the testing phase, the participants were presented with word/nonwords or grammatical/ungrammatical sentences in a randomized manner through DMDX software.

3.6.1.1 Synthetic word strings: The participants were instructed to respond by pressing '1' on the keyboard when they hear a word and '0' when they hear a 'nonword'.

3.6.1.2 Synthetic sentences: The participants were instructed to respond by pressing ‘1’ on the keyboard when they hear a grammatically correct sentence, i.e. one which seems to follow the pattern of the training stimulus; and ‘0’ when they hear a sentence which is ungrammatical (does not follow the training pattern).

Response acquisition was controlled by the DMDX software. Response error rates were calculated via DMDX and analyzed further to correlate the results with OAEs.

Chapter 4

Results

The primary objectives of the study were to delineate the effects of age on the incidental language learning tasks, and efferent inhibition of OAE, and find the relationship between language learning and inhibition of OAEs. A total of 91 individuals participated in the study. The data, thus obtained, was analyzed for normality and homogeneity of variance using SPSS software (version 20.0). Boxplots of the data were visualized to identify outliers. After the removal of initial outliers, usable data of 90 individuals was obtained. Shapiro-Wilk test of normality revealed that the samples were normality distributed and Levene's test showed that the data satisfied the criteria for homogeneity of variance; hence, parametric tests were used for further comparisons. Descriptive statistics were performed to obtain the mean values and standard deviation for all the parameters and are summarized in Table 4.1.

Table 4.1
Mean, median and standard deviation values for data

Age group		Inhibition amplitude (dB)	Word scores (%)	Sentence scores (%)
Young adults (N=40)	Mean	1.220	56.87	57.87
	Std. Deviation	.7144	7.981	7.415
	Median	1.100	60.00	55.00
Middle aged adults (N=20)	Mean	1.205	51.50	52.75
	Std. Deviation	.7119	12.258	9.244
	Median	1.050	50.00	50.00
Elder adults (N=30)	Mean	1.263	51.17	51.33
	Std. Deviation	.6851	8.972	7.649
	Median	1.250	52.50	50.00
Total (N=90)	Mean	1.231	53.78	54.56
	Std. Deviation	.6966	9.695	8.402
	Median	1.100	55.00	55.00

According to the aims of the study the results have been divided into 4 parts discussed in this section under the following headings:

4.1 Effect of age on statistical language learning score: word stimuli

4.2 Effect of age on statistical language learning score: sentence stimuli

4.3 Effect of age on contralateral inhibition of TEOAE

4.4 Correlation between CITEOAE and statistical language learning

4.1 Effect of age on statistical language learning: word stimuli

Figure 4.1 shows mean word learning scores along with one standard deviation. From the figure it can be seen that there is a reduction of scores with the advancing age. To check the significance of these differences, one-way ANOVA was performed with age groups as between the subject factor. It was observed that there was a significant main effect of age [f (2,87)= 3.923, p=0.023, effect size (η^2 = 0.0827)] on word learning scores. Post hoc analysis with Bonferroni's correction showed that YNH group performed significantly better compared to ENH group. (p = 0.041). However, no significant difference was found between YNH with MNH group, or between MNH group and ENH group.

4.2 Effect of age on statistical language learning score: sentence stimuli

Figure 4.1 shows mean percentage scores on the sentence task along with one standard deviation across three age groups. From the figure it was observed that scores on the sentence task decreased with age. One-way ANOVA was performed on raw scores to assess the significance of this difference with age group as the between-subject factor. Results showed a significant main effect of age [f (2,87) = 6.507, p=0.002, effect size (η^2 = 0.1301)] on learning scores. Post hoc analysis with Bonferroni's correction showed that YNH group performed significantly better compared to ENH group (p = 0.003). Scores of the MNH group differed from the YNH group with confidence levels at the lower border of significance (p = 0.061). The MNH and ENH groups obtained lower scores than YNH group. Comparison between scores of MNH group with ENH group did not yield statistically significant differences.

Figure 4.1 represents mean scores in percentage obtained on the word and sentence tasks across the three age groups. Error bars represent ±1SD.

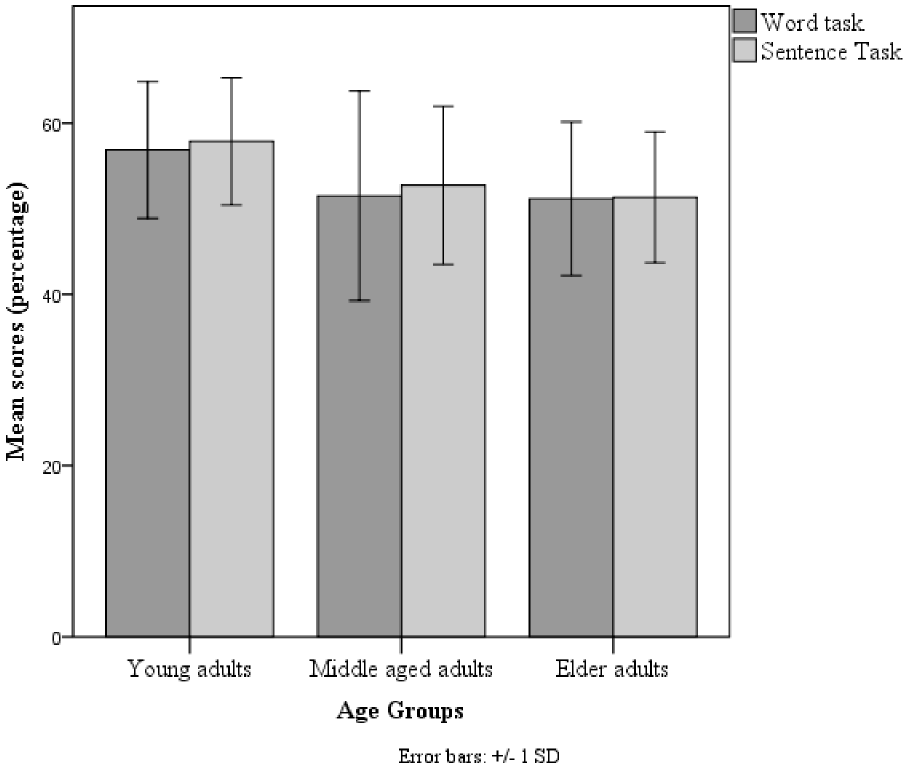

Figure 4.1 Mean scores of both statistical language learning tasks across the three age groups.

4.3 Effect of age on contralateral inhibition of TEOAE.

One-way ANOVA did not show a significant main effect of age [f (2,87) = 0.050, $p > 0.005$, effect size ($\eta^2 = 0.0011$)] on contralateral inhibition of TEOAEs

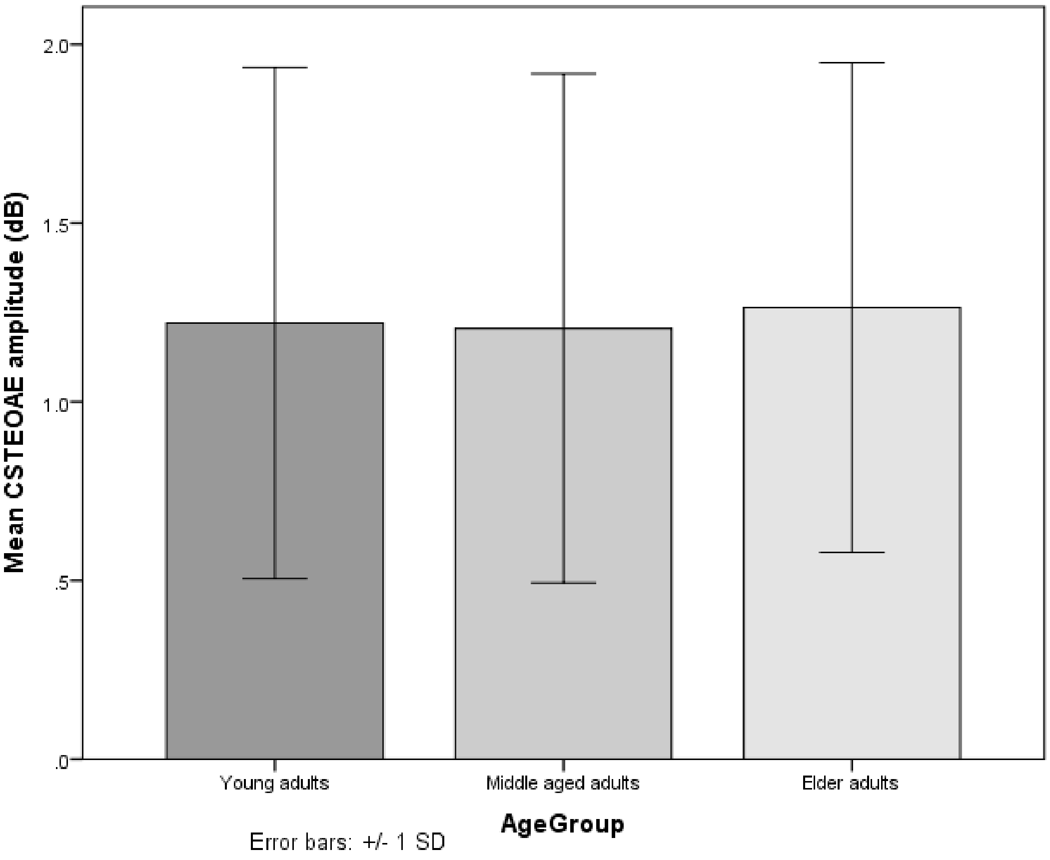

Fig 4.2 Mean amplitude of CITEOAE in dB across age groups. Error bars represent ±1 SD

4.4 Relationship between contralateral inhibition of TEOAE and statistical language learning

To explore the relationship between these two variables Pearson's Product Moment correlation analyses was performed. Correlation between scores of the incidental language learning tasks and CITEOAE across age was obtained using bivariate analysis. Pearson's correlation coefficient was calculated by analyzing three variables; namely scores of word task, sentence task, and CITEOAE amplitude. There was no significant correlation observed between CITEOAE amplitude with scores of word task [r (88) = -

0.053, p > 0.005] or with sentence task [r (88) = -0.079, p > 0.005]. Table 4.2 shows the results of Bivariate analysis. Tables 4.3 to 4.5 summarize the relationship between the above mentioned across the three age groups.

Table 4.2

Pearson's Product-Moment correlation coefficients

		Word task Scores	Sentence task Scores
CITEOAE Amplitude (dB)	Pearson Correlation	-.053	-.079
	Sig. (2-tailed)	.617	.458

Figures 4.3 and 4.4 depict scatter plots denoting the relationship of CITEOAE with word task scores, and CITEOAE with sentence task scores respectively. Fit lines signify overall trend, as well as trend across age groups.

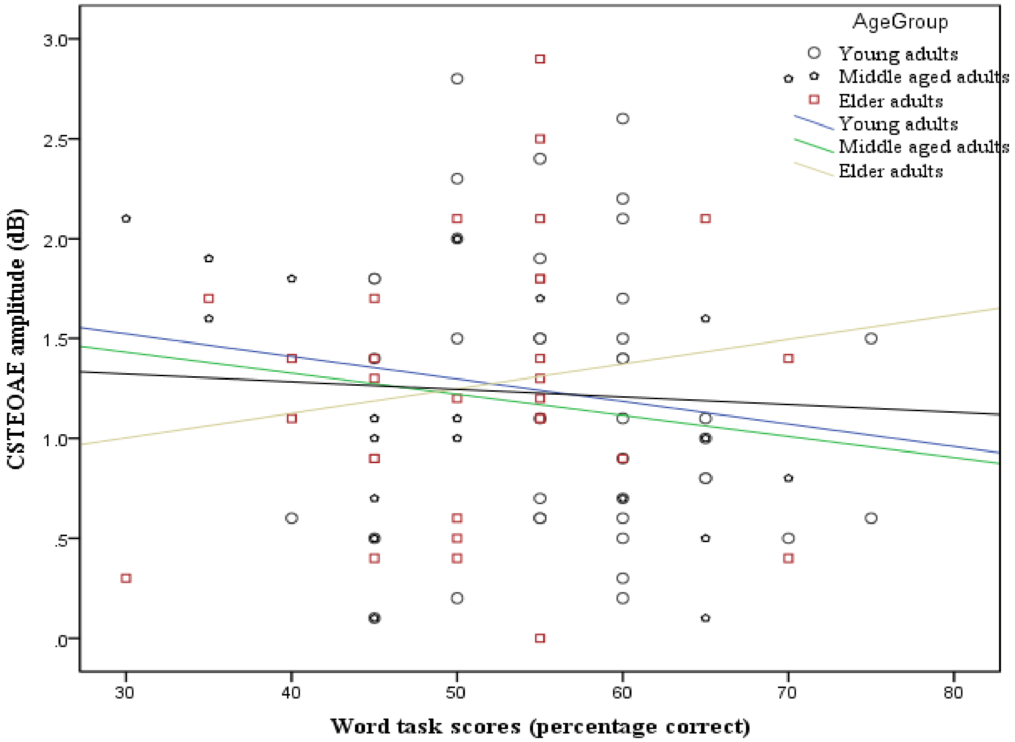

Fig 4.3 Scatter plot showing relationship between CITEOAE amplitude and percentage correct scores on the word task across the three age groups

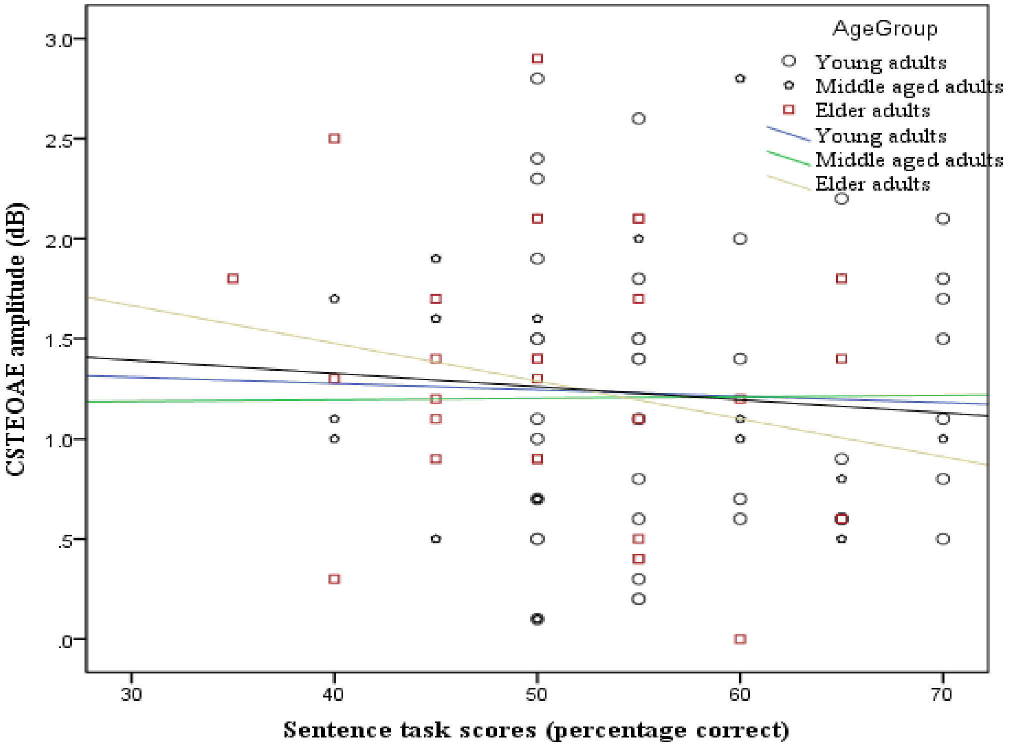

Fig 4.4 Scatter plot showing relationship between CITEOAE amplitude and percentage correct scores on the sentence task across age groups

From the above results it is evident that there is no relationship between amplitude of efferent inhibition and scores obtained on incidental language learning tasks.

Chapter 5

DISCUSSION

The purpose of the study was to examine the effects of age on the incidental language learning tasks, and efferent inhibition of OAE, and to examine the relationship between language learning and contralateral inhibition of OAE. The results obtained above will be discussed accordingly.

5.1 Efferent inhibition of TEOAE

As mentioned earlier, a number of factors can affect the measurement of CITEOAE including aging, right ear advantage, etc. as well as procedural variables such as probe placement, background noise and so on. These variables have been controlled to a great extent in the study. Majority of the subjects included in the study were right-handed with general preference for using the right side. Therefore, right ear OAEs were measured for all individuals. In order to control for effects of attentions the subjects were instructed not to attend to the stimuli. Probe placement were unaltered for the two test conditions – quiet and noise. Also, the tests were carried out in a randomized manner. In this study we obtained mean CITEOAE values = 1.231 (±1 SD = 0.6966) which are comparable to previous studies. Mishra and Lutman (2013) measured the absolute CITEOAE amplitude to range from 0.86 to 1.47 dB. Similar results have been reported in other studies as well (Collet, Veuillet, Bene, & Morgan, 1992; Giraud et. al. 1995).

CITEOAE amplitudes were compared across the three age groups. No significant age effect was found across the three groups. These findings are in accordance with studies by Quaranta, Debole and Di Girolamo (2001), Parthasarthy (2001) and Yilmaz et al (2007). Quaranta et al (2001) measured the inhibition amplitude of TEOAE on subjects aged 20 to 78 years, divided into five groups based on age, with white noise as the suppressor stimulus. No significant age effect was found across the age groups for TEOAE inhibition amplitude. Parthasarathy (2001) studied the effects of age on TEOAE inhibition amplitude in the age range of 20 to 79 years and found that mean amplitude of inhibition of TEOAEs showed minor variation across the age groups upto 60 years of age, followed by a sharp decline from 60-79 years of age. However, no significant effect of age on CITEOAE was observed till 60 years of age. Yilman et al. (2007) observed an age-related drop in absolute amplitudes of TEOAE with age. The authors also noted a decline in mean amplitude of inhibition with age, however, this decline was not found to be statistically significant.

The reasons for such findings are unclear, and few studies are observed in literature where there is no significant effect of efferent inhibition across age. The above authors have attributed their findings to procedural variables. Contradictory results have been found in other studies (Abdala, Dhar, Ahmadi, & Luo, 2014; Jacobson, Kim, Romney, Zhu, & Frisina, 2003; Kim, Frisina[a], Frisina, & Chair, 2002; Tadros et al., 2005) which could be attributed to smaller sample sizes included in the study.

5.2 Statistical language learning

Statistical language learning was studied using two paradigms that have been previously established in literature – word level and sentence level tasks (Newport & Aslin, 2004; Saffran & Saffran, 2003; Gomez, Gerken, & Schvaneveldt, 2000). There is dearth of literature comparing language acquisition across age in adults. There are also large variations in paradigms and tasks used across the studies (Dienes, 1978; R L Gomez et al., 2000; Romberg & Saffran, 2013). There is no one standardized test to assess statistical language learning. Hence, it is difficult to compare raw scores obtained with previous literature.

Nonetheless, we have observed similarities in results in terms of success with implicit language learning (Abla, Katahira, & Okanoya, 2008; Gomez & Gerken, 1999; Saffran, 2003). In our study we observed mean scores on each task to be well above chance level, especially for the younger participants. For the ENH group, scores were close to chance level.

We also obtained a slow declining trend in the scores across the age groups indicating that the ability to acquire a new language decreases with age. There was no significant difference between YNH and MNH group, or MNH and ENH group. However, statistically significant scores were obtained between the YNH and ENH group. This can be attributed to age related decline in cognition and working memory capacity. A compilation of research by Baddeley and colleagues provide evidence of the link between language learning and working memory (Baddeley, 2010). This model given by Baddeley provides neuropsychological evidence for the relationship and has implication for both native and second language learning. It also aids in correlating the model with both normal and disordered language functions. Aging affects working memory by reduction is speech of processing, reduction in task precision and execution of elementary operations (Salthouse, 1991; Salthouse & Babcock, 1991). These authors compared working memory performance across a wide age range (20 to 87 years) with large sample size (>200). They hypothesize that reduction in working memory capacity may reflect reduced storage capacity, processing efficiency, coordination effectiveness, and simple comparison speed across tasks.

Thus, reduction in scores across age in language learning tasks can be attributed to cognitive decline and working memory. Other variables influencing the tasks include attention, comprehension of the instruction and motivation. Barr and Giambra (1990) studied the effect of age on auditory selective attention and found that older individuals have difficulty paying directed attention to auditory tasks. Attention has a direct effect on learning of novel linguistic patterns as shown by earlier studies (Toro, Sinnett, & Soto-Faraco, 1997). In this study, Toro and colleagues studied the effect of divided attention within and across modalities on word segmentation tasks. It was found that inattention can have adverse effects on speech segmentation based on statistical learning with scores dropping to chance level.

5.3 Correlation between CITEOAE and perceptual learning

The final objective of this study was to examine the relationship between efferent inhibition and perceptual learning. We aimed to investigate whether good language learners show physiological evidence of plasticity at the level of the brainstem. A number of studies (Jessica de Boer & Thornton, 2008; Kumar et al., 2010) have drawn positive correlations between short term perceptual learning and efferent inhibition mechanisms. However, in the current investigation we did not observe any significant correlation between amplitudes of efferent inhibition and scores on language learning tasks.

The neurobiological mechanisms involved in incidental language learning have not been clearly established. Even so, this mechanism involves diffused activation at the level of the fronto-parietal areas of the cerebral hemisphere (Abla et al., 2008). Hence, subcortical measurements may not provide a wholistic view of the subtle mechanisms of probabilistic learning. Studies on word segmentation tasks performed using evoked potentials have revealed presence of activation patterns corresponding to the ability to differentiate grammatical and ungrammatical segments (Teinonen et al., 2009). This study uses event related potentials to conclude that the neonatal brain responds differently to syllables according to their position within pseudo words. A study by Cunillera, Toro, Sebastián-Gallés and Rodríguez-Fornells, (2006) viewed the N400 and P2 responses of event related potentials (ERPs) to illustrate the responses obtained for word segmentation tasks. The subjects were able to distinguish word versus non-word stimuli and displayed corresponding changes in ERP amplitudes and latencies.

Performance of statistical language learning tasks using an auditory as well as visual paradigm were correlated with working memory, auditory processing, evoked potential responses and frequency discrimination (Vasuki, Sharma, Demuth, & Arciuli, 2016). On comparing performance across two groups – musicians and non-musicians, the authors found that musicians possessed a significant advantage over non-musicians in the auditory statistical learning task. They also obtained higher scores compared to non-musicians on some tasks of working memory. However, when statistical language learning efficiency was evaluated using behavioral and electrophysiological measures, it was found that electrophysiological measures provided a better indication of group differences. Behavioral tests showed less distinct group effects on the statistical language learning task, with scores closer to chance level. On the other hand, significant differences were observed in evoked potential studies as well as some tasks of auditory processing in musicians. The authors have stated that the mechanisms responsible for implicit learning are independent of general cognitive abilities, as well as measures of verbal reasoning and intelligence.

The above review indicates that there is much to be understood about the physiological phenomena underlying implicit language acquisition. This involves higher order cognitive processing and contributions by multiple neuronal populations. Thus, peripheral measures like OAEs prove to be insufficient in correctly observing the effects of the ability of perceptual learning, and corresponding plasticity in the auditory nervous system.

Chapter 6

SUMMARY AND CONCLUSION

90 subjects with normal hearing sensitivity were recruited for the study. The subjects were divided into three groups on the basis of age – young normal hearing, middle-aged normal hearing and elder normal hearing individuals. TEOAEs were measured for all the subjects in quiet and in the presence of contralateral white noise. Contralateral inhibition of OAE was calculated by subtracting the global amplitudes in quiet from global amplitudes in noise.

The subjects underwent short duration of training (10 minutes each) on two artificial language learning tasks – word segmentation and finite structure grammar learning. After the brief period of training, practice items were presented to the subjects. After ensuring that that subjects understood the instruction a 2-minute test was presented in which subjects had to differentiate between *word and non-word*, or *grammatical and ungrammatical sentence* based on the training. The subjects obtained above chance level scores indicating an ability to acquire linguistic rules using artificial language.

The scores on both tasks were compared across age groups using one-way ANOVA. Significant main effect of age was observed for both tasks. That is, scores on artificial language learning tasks reduced with age, with YNH group obtaining the highest scores. Lowest scores were obtained by the ENH group. The findings indicate that aging affects the mechanisms of language learning which could be attributed to reduction in working memory capacity and age related cognitive decline. However, there was no effect of age on contralateral inhibition of TEOAEs. Pearson's Product Moment correlation analysis was carried out to explore the relationship between efferent inhibition and artificial language learning. Results showed no significant correlation between artificial language learning and inhibition of TEOAE. The results indicate that statistical language learning may involve higher order processing which cannot be estimated adequately though OAE.

Future directions:

- It may be worthwhile to observe changes in measures of brainstem processing over a period of training across a few weeks in relation to language acquisition.
- There is also scope to evaluate changes at the physiological level using auditory evoked responses, especially long latency event related potentials.
- Learning of transitional probabilities can be assessed using stimuli such as speech or tone sequences in different populations such as musicians, individuals with learning difficulties, and individuals with hearing impairment.

REFERENCES

Abdala, C. (1998). A developmental study of distortion product otoacoustic emission (2f1-f2) suppression in humans. *Hearing Research*, *121*(1–2), 125–38. https://doi.org/http://dx.doi.org/10.1016/S0378-5955(98)00073-2

Abdala, C., & Chatterjee, M. (2003). Maturation of cochlear nonlinearity as measured by distortion product otoacoustic emission suppression growth in humans. *The Journal of the Acoustical Society of America*, *114*(2), 932–943. https://doi.org/10.1121/1.1590973

Abdala, C., Dhar, S., Ahmadi, M., & Luo, P. (2014). Aging of the medial olivocochlear reflex and associations with speech perception. *The Journal of the Acoustical Society of America*, *135*(2), 754–765. https://doi.org/10.1121/1.4861841

Abla, D., Katahira, K., & Okanoya, K. (2008). On-line Assessment of Statistical Learning by Event-related Potentials. *Journal of Cognitive Neuroscience*, *20*(6), 952–964. https://doi.org/10.1162/jocn.2008.20058

Ahissar, M., & Hochstein, S. (2004). The reverse hierarchy theory of visual perceptual learning, *8*(10). https://doi.org/10.1016/j.tics.2004.08.011

Ahissar, M., Nahum, M., Nelken, I., & Hochstein, S. (2009). Reverse hierarchies and sensory learning. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *364*(1515), 285–299. https://doi.org/10.1098/rstb.2008.0253

Aidan, D., Lestang, P., And, P. A., & Bonfils, P. (1997). Characteristics of Transient-evoked Otoacoustic Emissions (TEOEs) in Neonates. *Acta Oto-Laryngologica*, *117*(1), 25–30. https://doi.org/10.3109/00016489709117986

ASHA. (2005). *Guidelines for Manual Pure-Tone Threshold Audiometry*. https://doi.org/10.1044/policy.GL2005-00014

Baddeley, A. (2003). Working memory and language : an overview, *36*, 189–208. https://doi.org/10.1016/S0021-9924(03)00019-4

Baddeley, A. (2010). Working memory. *Current Biology : CB*, *20*(4), R136-40. https://doi.org/10.1016/j.cub.2009.12.014

Baddeley, A., Papagno, C., & Vallar, G. (1988). When long-term learning depends on short-term storage. *Journal of Memory and Language*, *27*(5), 586–595. https://doi.org/10.1016/0749-596X(88)90028-9

Banai, K., & Ahissar, M. (2009). Perceptual learning as a tool for boosting working memory among individuals with reading and learning disability. *Learning & Perception*, *1*(1), 115–134. https://doi.org/10.1556/LP.1.2009.1.9

Barr, R. A., & Giambra, L. M. (1990). Age-related decrement in auditory selective attention. *Psychology and Aging*, *5*(4), 597–599. https://doi.org/10.1037//0882-7974.5.4.597

Berlin, C. I., Hood, L. J., Hurley, A., & Wen, H. (1994). Contralateral Suppression of Otoacoustic Emissions: An Index of the Function of the Medial Olivocochlear System. *Otolaryngology-Head and Neck Surgery*, *110*(1), 3–21. https://doi.org/10.1177/019459989411000102

Berninger, E. (2007). Characteristics of normal newborn transient-evoked otoacoustic emissions: Ear asymmetries and sex effects. *International Journal of Audiology*, *46*(11), 661–669. https://doi.org/10.1080/14992020701438797

Burguetti, F. A. R., & Carvallo, R. M. M. (2008). Efferent auditory system: its effect on auditory processing. *Brazilian Journal of Otorhinolaryngology*, *74*(5), 737–45. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/19082357

Ciuman, R. R. (2010). The efferent system or olivocochlear function bundle - fine regulator and protector of hearing perception. *International Journal of Biomedical Science : IJBS*, *6*(4), 276–88. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/23675203

Collet, L., Moulin, A., Morlet, T., Giraud, A. L., Micheyl, C., & Chéry-croze, S. (1994). Contralateral auditory stimulation and otoacoustic emissions: a review of basic data in humans. *British Journal of Audiology*, *28*(4–5), 213–218. https://doi.org/10.3109/03005369409086570

Collet, L., Veuillet, E., Bene, J., & Morgan, A. (1992). Effects of contralateral white noise on click-evoked emissions in normal and sensorineural ears: Towards an exploration of the medial olivocochlear system. *International Journal of Audiology*, *31*(1), 1–7. https://doi.org/10.3109/00206099209072897

Cunillera, T., Toro, J. M., Sebastián-Gallés, N., & Rodríguez-Fornells, A. (2006). The effects of stress and statistical cues on continuous speech segmentation: An event-related brain potential study. *Brain Research*, *1123*(1), 168–178. https://doi.org/10.1016/j.brainres.2006.09.046

de Boer, J., & Thornton, A. R. D. (2008). Neural Correlates of Perceptual Learning in the Auditory Brainstem: Efferent Activity Predicts and Reflects Improvement at a Speech-in-Noise Discrimination Task. *Journal of Neuroscience*, *28*(19), 4929–4937. https://doi.org/10.1523/JNEUROSCI.0902-08.2008

Delano, P. H., & Elgoyhen, A. B. (2016). Editorial: Auditory Efferent System: New Insights from Cortex to Cochlea. *Frontiers in Systems Neuroscience*, *10*(June), 1–2. https://doi.org/10.3389/fnsys.2016.00050

Dienes, Z. (1978). Artificial grammar learning. *Time*. https://doi.org/10.1075/sibil.48.11zio

Driscoll, C., Kei, J., & McPherson, B. (2000). Transient evoked otoacoustic emissions in 6-year-old school children: a normative study. *Scandinavian Audiology*, *29*(2), 103–110. https://doi.org/10.1080/010503900424516

Forster, K. I. F. J. C. (2003). DMDX: A Windows display program with millisecond accuracy. *Behavior Research Methods, Instruments, & Computers*, *35*(1), 116–124. Retrieved from http://www.indiana.edu/~clcl/Q550_WWW/Papers/ForsterEtAl%282003%29.pdf

Froehlich, P., Collet, L., & Morgon, A. (1993). Transiently evoked otoacoustic emission amplitudes change with changes of directed attention. *Physiology & Behavior*, *53*(4), 679–682. https://doi.org/10.1016/0031-9384(93)90173-D

Gargeshwari, A., Kumar, A. U. (2016). *Test Retest repeatability of contralateral inhibition of trainsent evoked Otoacoustic emissions*. All India Institute of Speech and Hearing. Retrieved from http://203.129.241.86:8080/digitallibrary/AdvanveResult.do

Giard, M.-H., Collet, L., Bouchet, P., & Pernier, J. (1994). Auditory selective attention in the human cochlea. *Brain Research*, *633*(1–2), 353–356. https://doi.org/10.1016/0006-8993(94)91561-X

Giraud, A. L., Collet, L., Chéry-Croze, S., Magnan, J., & Chays, A. (1995). Evidence of a medial olivocochlear involvement in contralateral suppression of otoacoustic emissions in humans. *Brain Research*, *705*(1–2), 15–23. https://doi.org/10.1016/0006-8993(95)01091-2

Gomez, R. L., & Gerken, L. (1999). Artificial grammar learning by 1-year-olds leads to specific and abstract knowledge. Retrieved from http://ling.umd.edu/~jlidz/Teaching/SP06Seminar/Gomez-Cognition-1999.pdf

Gomez, R. L., Gerken, L., & Schvaneveldt, R. W. (2000). The basis of transfer in artificial grammar learning. *Memory & Cognition*, *28*(2), 253–263. https://doi.org/10.3758/BF03213804

Gordon-Salant Sandra, F. R. D. (2010). *The Aging Auditory System - Google Books*. Retrieved from_https://books.google.co.in/books?hl=en&lr=&id=oMsXWRjHRfwC&oi=fnd&pg=PA1&dq=aging+and+the+efferent+auditory+system&ots=qyhrSQdV5t&sig=qA0V0aNytVL070N-9QypraaqJH8#v=onepage&q=aging and the efferent auditory system&f=false

Guinan, J. J. (1996). Physiology of olivocochlear efferents. *The Cochlea*, (Rasmussen 1960), 435–502. https://doi.org/10.1007/978-1-4612-0757-3

Guinan, J. J. (2006). Olivocochlear Efferents: Anatomy, Physiology, Function, and the Measurement of Efferent Effects in Humans. *Ear and Hearing*, *27*(6), 589–607. https://doi.org/10.1097/01.aud.0000240507.83072.e7

Gupta, D., & Vanaja, C. S. (2016). High frequency tympanometry findings in neonates and infants with normal hearing-A normative study. *International Journal of Community Health and Medical Research*, *22*. Retrieved from http://ijchmr.com/uploadfiles/12346342.20160406052632.PDF

Ha, A., & Hu, J. Establishing Clinical Normative Data for Wideband Tympanometry Measurements. *Canadian Audiologist*, *3*(6). Retrieved from http://canadianaudiologist.ca/issue/volume-3-issue-6-2016/clinical-normative-data-feature/

Irving, S., Moore, D. R., Liberman, M. C., & Sumner, C. J. (2011). Olivocochlear Efferent Control in Sound Localization and Experience-Dependent Learning. *Journal of Neuroscience*, *31*(7), 2493–2501. https://doi.org/10.1523/JNEUROSCI.2679-10.2011

Jacobson, M., Kim, S., Romney, J., Zhu, X., & Frisina, R. D. (2003). Contralateral suppression of distortion-product otoacoustic emissions declines with age: A comparison of findings in CBA mice with human listeners. *The Laryngoscope*, *113*(10), 1707–1713. https://doi.org/10.1097/00005537-200310000-00009

Jerger, J. (1970). Clinical Experience With Impedance Audiometry. *Archives of Otolaryngology - Head and Neck Surgery*, *92*(4), 311–324. https://doi.org/10.1001/archotol.1970.04310040005002

Kei, J., McPherson, B., Smyth, V., Latham, S., & Loscher, J. (1997). Transient Evoked Otoacoustic Emissions in Infants: Effects of Gender, Ear Asymmetry and Activity Status. *International Journal of Audiology*, *36*(2), 61–71. https://doi.org/10.3109/00206099709071961

Kemp, D. T. (1979). Evidence of mechanical nonlinearity and frequency selective wave amplification in the cochlea. *Archives of Oto-Rhino-Laryngology*, *224*(1–2), 37–45. https://doi.org/10.1007/BF00455222

Kemp, D. T. (1986). Otoacoustic emissions, travelling waves and cochlear mechanisms. *Hearing Research*, *22*(1–3), 95–104. https://doi.org/10.1016/0378-5955(86)90087-0

Kemp, D. T. (2002). Otoacoustic emissions , their origin in cochlear function , and use, 223–241.

Keppler, H., Dhooge, I., Maes, L., D'haenens, W., Bockstael, A., Philips, B. Vinck, B. (2010). Transient-evoked and distortion product otoacoustic emissions: A short-term test-retest reliability study. *International Journal of Audiology*, *49*(2), 99–109. https://doi.org/10.3109/14992020903300431

Kim, S., Frisina, D. R., Frisina, R. D., & Chair, O. A. (2006). Effects of Age on Speech Understanding in Normal Hearing Listeners: Relationships Between the Auditory Efferent System and Speech Intelligibility in Noise. Retrieved from http://www.isca-speech.org/archive

Kraus, N., Slater, J., Thompson, E. C., Hornickel, J., Strait, D. L., Nicol, T., & White-Schwoch, T. (2014). Music enrichment programs improve the neural encoding of speech in at-risk children. *The Journal of Neuroscience*, *34*(36), 11913–8. https://doi.org/10.1523/JNEUROSCI.1881-14.2014

Krishnan, A., Xu, Y., Gandour, J., & Cariani, P. (2005). Encoding of pitch in the human brainstem is sensitive to language experience. *Cognitive Brain Research*, *25*(1), 161–168. https://doi.org/10.1016/J.COGBRAINRES.2005.05.004

Kumar, A. U., Hegde, M., & Mayaleela. (2010). Perceptual learning of non-native speech contrast and functioning of the olivocochlear bundle. *International Journal of Audiology*, *49*(7), 488–496. https://doi.org/10.3109/14992021003645894

Mandikal Vasuki, P. R., Sharma, M., Demuth, K., & Arciuli, J. (2016). Musicians' edge: A comparison of auditory processing, cognitive abilities and statistical learning. *Hearing Research*, *342*, 112–123. https://doi.org/10.1016/j.heares.2016.10.008

Meric, C., & Collet, L. (1992). Visual attention and evoked otoacoustic emissions: A slight but real effect. *International Journal of Psychophysiology*, *12*(3), 233–235. https://doi.org/10.1016/0167-8760(92)90061-F

Meric, C., & Collet, L. (1994). Differential effects of visual attention on spontaneous and evoked otoacoustic emissions. *International Journal of Psychophysiology*, *17*(3), 281–289. https://doi.org/10.1016/0167-8760(94)90070-1

Mirman, D., Magnuson, J. S., Estes, K. G., & Dixon, J. A. (2009). adults, *108*(1), 1–9. https://doi.org/10.1016/j.cognition.2008.02.003.The

Mishra, S. K., & Lutman, M. E. (2013). Repeatability of Click-Evoked Otoacoustic Emission-Based Medial Olivocochlear Efferent Assay. *Ear and Hearing*, *34*(6), 789–798. https://doi.org/10.1097/AUD.0b013e3182944c04

Newport, E. L., & Aslin, R. N. (2004). Learning at a distance I. Statistical learning of non-adjacent dependencies. *Cognitive Psychology*, *48*(2), 127–162. https://doi.org/10.1016/S0010-0285(03)00128-2

Parbery-Clark, A., Anderson, S., Hittner, E., & Kraus, N. (2012). Musical experience strengthens the neural representation of sounds important for communication in middle-aged adults. *Frontiers in Aging Neuroscience*, *4*(OCT), 1–12.

https://doi.org/10.3389/fnagi.2012.00030

Parbery-Clark, A., Anderson, S., & Kraus, N. (2013). Musicians change their tune: How hearing loss alters the neural code. *Hearing Research*, *302*, 121–131. https://doi.org/10.1016/j.heares.2013.03.009

Parbery-Clark, A., Strait, D. L., Hittner, E., & Kraus, N. (2013). Musical Training Enhances Neural Processing of Binaural Sounds. *The Journal of Neuroscience*, *33*(42), 16741–16747. https://doi.org/10.1523/JNEUROSCI.5700-12.2013

Parthasarathy, T. K. (2001). Aging and contralateral suppression effects on transient evoked otoacoustic emissions. *Journal of the American Academy of Audiology*, *12*(2), 80–85.

Pavlovčinová, G., Jakubíková, J., š Trnovec, T., Lancz, K., Wimmerová, S., Š ovčíková, E., & Palkovičová, ubica. (2010). A normative study of otoacoustic emissions, ear asymmetry, and gender effect in healthy school children in Slovakia. https://doi.org/10.1016/j.ijporl.2009.11.002

Pothos, E. M. (2007). Theories of artificial grammar learning. *Psychological Bulletin*, *133*(2), 227–244. https://doi.org/10.1037/0033-2909.133.2.227

Probst, R., Lonsbury-Martin, B. L., & Martin, G. K. (1999). A review of otoacoustic emissions. *The Journal of the Acoustical Society of America*, *89*(5), 2027. https://doi.org/10.1121/1.400897

Quaranta, N., Debole, S., & Di Girolamo, S. (2001). Effect of Ageing on Otoacoustic Emissions and Efferent Suppression in Humans: Efectos de la edad en las emisiones otoacústicas y (EN LA) supresión eferente en humanos. *International Journal of*

Audiology, *40*(6), 308–312. https://doi.org/10.3109/00206090109073127

Rasmussen, G. L. (1946). The olivary peduncle and other fiber projections of the superior olivary complex. *The Journal of Comparative Neurology*, *84*(2), 141–219. https://doi.org/10.1002/cne.900840204

Reber, A. (1967). Implicit Learning and Tacit Knowledge . *JournalofExperimentalPsychology:General1989*,*118*(3),219–235. https://doi.org/10.1037/0096-3445.118.3.219

Romberg, A. R., & Saffran, J. R. (2013). All Together Now: Concurrent Learning of Multiple Structures in an Artificial Language. *Cognitive Science*, 1–31. https://doi.org/10.1111/cogs.12050

Saffran, J. R. (2003). Statistical language learning. *Current Directions in Psychological Science*, *12*(4), 110–114. https://doi.org/10.1111/1467-8721.01243

Saffran, J. R., Johnson, E. K., Aslin, R. N., & Newport, E. L. (1999). Statistical learning of tone sequences by human infants and adults. *Cognition*, *70*(1), 27–52. https://doi.org/10.1016/S0010-0277(98)00075-4

Saffran, J. R., Johnson, E. K., Aslin, R. N., & Newport, E. L. (1999). Statistical learning of tone sequences by human infants and adults. *Cognition*, *70*(1), 27–52.

Saffran, J. R., Newport, E. L., & Aslin, R. N. (1996). Word Segmentation: The Role of Distributional Cues. *Journal of Memory and Language*, *35*(4), 606–621. https://doi.org/10.1006/jmla.1996.0032

Saffran, J. R., & Saffran, J. R. (2003). Statistical language learning: mechanisms and constraints. *Current Directions in Psychological Science*, *12*(4), 110–114. https://doi.org/10.1111/1467-8721.01243

Salthouse, T. A. (1991). Mediation of Adult Age Differences in Cognition By Reductions in Working Memory and Speed of Processing. *Psychological Science*, *2*(3), 179–183. https://doi.org/10.1111/j.1467-9280.1991.tb00127.x

Salthouse, T. A., & Babcock, R. L. (1991). Decomposing adult age differences in working memory. *Developmental Psychology*, *27*(5), 763–776. https://doi.org/10.1037/0012-1649.27.5.763

Sanches, S. G. G., & Carvallo, R. M. (2006). Contralateral suppression of transient evoked otoacoustic emissions in children with auditory processing disorder. *Audiology & Neuro-Otology*, *11*(6), 366–72. https://doi.org/10.1159/000095898

Scharf, B., Magnan, J., Collet, L., Ulmer, E., & Chays, A. (1994). On the role of the olivocochlear bundle in hearing: A case study. *Hearing Research*, *75*(1–2), 11–26. https://doi.org/10.1016/0378-5955(94)90051-5

Shera, C. A., & Guinan, J. J. (1999). Evoked otoacoustic emissions arise by two fundamentally different mechanisms: A taxonomy for mammalian OAEs. Retrieved from http://web.mit.edu/apg/papers/shera-guinan-taxonomy-JASA99.pdf

Smith, D. W., Turner, D. a, & Henson, M. M. (2000). Psychophysical correlates of contralateral efferent suppression. I. The role of the medial olivocochlear system in “central masking” in nonhuman primates. *The Journal of the Acoustical Society of America*, *107*(2), 933–941. https://doi.org/10.1121/1.428274

Song, J. H., Skoe, E., Banai, K., & Kraus, N. (2012). Training to improve hearing speech in noise: Biological mechanisms. *Cerebral Cortex*, *22*(5), 1180–1190. https://doi.org/10.1093/cercor/bhr196

Strait, D. L., & Kraus, N. (2014). Biological impact of auditory expertise across the life span: Musicians as a model of auditory learning. *Hearing Research*, *308*, 109–121. https://doi.org/10.1016/j.heares.2013.08.004

Strait, D. L., Parbery-Clark, A., Hittner, E., & Kraus, N. (2012). Musical training during early childhood enhances the neural encoding of speech in noise. *Brain and Language*, *123*(3), 191–201. https://doi.org/10.1016/j.bandl.2012.09.001

Stuart, A., & Cobb, K. M. (2015). Reliability of measures of transient evoked otoacoustic emissions with contralateral suppression. *Journal of Communication Disorders*, *58*, 35–42. https://doi.org/10.1016/j.jcomdis.2015.09.003

Suga, N., Xiao, Z., Ma, X., & Ji, W. (2002). Plasticity and corticofugal modulation for hearing in adult animals. *Neuron*, *36*(1), 9–18. https://doi.org/10.1016/S0896-6273(02)00933-9

Tadros, S. F., Frisina, S. T., Mapes, F., Kim, S., Frisina, D. R., & Frisina, R. D. (2005). Loss of peripheral right-ear advantage in age-related hearing loss. *Audiology & Neuro-Otology*, *10*(1), 44–52. https://doi.org/10.1159/000082307

Tavartkiladze, G. A., Frolenkov, G. I., Kruglov, A. V., & Artamasov, S. V. (1994). Ipsilateral suppression effects on transient evoked otoacoustic emission. *British Journal of Audiology*, *28*(5--Apr), 193–204. https://doi.org/10.3109/03005369409086568

Teinonen, T., Fellman, V., Näätänen, R., Alku, P., & Huotilainen, M. (2009). Statistical language learning in neonates revealed by event-related brain potentials. *BMC Neuroscience 2009 10:1*, *10*(1), 21. https://doi.org/10.1186/1471-2202-10-21

Terreros, G., & Delano, P. H. (2015). Corticofugal modulation of peripheral auditory responses. *Frontiers in Systems Neuroscience, 9*(September), 134. https://doi.org/10.3389/fnsys.2015.00134

Toro, J. M., Sinnett, S., & Soto-Faraco, S. (2005). Speech segmentation by statistical learning depends on attention. https://doi.org/10.1016/j.cognition.2005.01.006

Vallar, G., Corno, M., & Basso, A. (1992). Auditory and Visual Verbal Short-Term Memory in Aphasia. *Cortex*, *28*(3), 383–389. https://doi.org/10.1016/S0010-9452(13)80148-7

Venkatesan, S. (2009). ethical guidelines for bio-behavioral research involving human subjects. *All India Institute of Speech and Hearing*. Retrieved from http://asa.scitation.org/doi/10.1121/1.1908495

Yilmaz, S. T., Sennaroğlu, G., Sennaroğlu, L., & Köse, S. K. (2007). Effect of age on speech recognition in noise and on contralateral transient evoked otoacoustic emission suppression. *The Journal of Laryngology & Otology*, *121*(11), 1029–1034. https://doi.org/10.1017/S0022215107006883

Zhao, W., & Dhar, S. (2011). Fast and slow effects of medial olivocochlear efferent activity in humans. *PLoS ONE*, *6*(4). https://doi.org/10.1371/journal.pone.0018725

Zurek, P. M. (1985). Acoustic emissions from the ear: A summary of results from humans and animals. *The Journal of the Acoustical Society of America*, *78*(1), 340–344. https://doi.org/10.1121/1.3924