EFFECT OF FAMILIARIZATION TO ODDBALL PARADIGM ON P300

Sam Publius A.

16AUD025

This Dissertation is submitted as part-fulfillment

For the Degree of Master of Science in Audiology

University of Mysuru, Mysuru

All India Institute of Speech and Hearing

Manasagangothri, Mysuru – 570006

April-2018

CERTIFICATE

This is to certify that this dissertation entitled '**Effect of Familiarization to Oddball Paradigm on P300'** is the bonafide work submitted in part fulfillment for the Degree of Master of Science (Audiology) of the student with Registration No: **16AUD025**. 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.

Dr. S. R. Savithri

Director

Mysuru — All India Institute of Speech and Hearing

April 2018 — Manasagangothri, Mysuru- 570 006

CERTIFICATE

This is to certify that this dissertation entitled '**Effect of Familiarization to Oddball Paradigm on P300'** has been prepared under my supervision and guidance. It is also certified that this has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Dr. Sandeep M.

Guide

Reader in Audiology

Department of Audiology

All India Institute of Speech and Hearing

Manasagangothri, Mysuru- 570006.

Mysuru,

April 2018.

DECLARATION

This is to certify that this Master's dissertation entitled **'Effect of Familiarization to Oddball Paradigm on P300'** is the result of my own study under the guidance of Dr. Sandeep M., Reader in Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysuru, and has not been submitted earlier in other University for the award of any Diploma or Degree.

Mysuru **Register No: 16AUD025**

April 2018

Acknowledgement

*I thank **YHWH Elohim** who is the light for my path in this great unknown, for his unending mercies and whom I believe is leading me into all truth.*

My heartfelt gratitude to my beloved parents for all that they do, for their love, prayers and sacrifices, I cannot imagine my world without them. I thank my sister for putting up with possibly the most not so good brother on planet earth, I wish to change.

I thank my guide Dr. Sandeep Maruthy who is a great source of inspiration, he is one of the most optimistic and kind person I have known, a fine teacher etc. etc. etc. He is awesome.

I thank all my teachers who have played a role in molding and shaping me. I thank Anup sir who was always there to help when I needed him to open the department. I thank Sharath sir, Nike sir, Srikar sir and Vikas sir for their goodwill and help.

I thank Nikhil and Jim who have been my go to people in college. Last but not the least, I extend my gratitude to all my friends in college and well-wishers.

.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1

INTRODUCTION

P300 is an event-related response that is majorly dependent on participant attention to certain auditory stimuli and it is an endogenous response (Polich, 2007). P300 is typically recorded using special stimulus conditions such as oddball paradigm, and is essentially a component within an extended ALR time frame. Auditory late responses are generated from a frequent or predictable stimulus or the standard signal. The positive deflection in the latency region of 300 ms are generated from the oddball or target signal-produces which are infrequent (rare), unpredictable (presented randomly) or different (deviant) in some way from the first signal. The response are referred to as P300, because it is present in the region of 300 ms, and sometimes referred as P3 wave, because it forms the third major positive voltage component after ALR waves, P1 and P2. However, P300 may be present in normal subjects as early as 250 msor as late as 400 ms, and may not necessarily be the third major component in the waveform.

Zhang and Kourtzi (2010) proposed two mechanisms of perceptual learning: the feedback-guided attentional process is believed to lead to feature-dependent learning, while passive exposure to stimuli is hypothesized to lead to learning that can be generalized to untrained features. It is possible to tap these two types of auditory perceptual learning by measuring P300. Auditory training causes both long term and short-term plasticity changes which can be reflected in the P3a and P3b responses (Uther,Kujala, Huotilainen, , &Näätänen, 2006). Neural plasticity, one of the inherent characteristics of the central nervous system, defines a changing pattern associated with neural form and its connections-based behavioral and learning experience through life (Eggermont, 1990; Rubel,1978; Gilbert, Sigman& Crist, 2001). Auditory training through repetitive listening tasks over a period of time causes alterations in plasticity in the human central auditory system (Tremblay, 2007)

The amplitude and latency of P300 has been shown to berelated to working memory of an individual. Nittono, Nageishi, Nakajima and Ullsperger(1999) assessed working memory capacity using a reading span test and found that the participants with high reading span test produced larger P300s than did those with low reading span in the reading task. It was suggested that individual differences in working memory capacity would affect initial stages of information processing as early as 300 ms after stimulus onset.

1.1 Justificationfor the Study

Familiarity of a complex environmental sound influences several stages of auditory processing outside the focus of attention (Kirmse, Jacobsen&Schröger, 2009). Kirmseet al.(2009) studied the influence of familiarity of an environmental sound on sound processing outside the focus of attention and found that the familiar sound elicited a frontocentrally enhanced P2 and an additional P250. Although scalp-recorded ERPs have been pivotal in identifying physiological correlates of auditory perceptual learning (Brattico, Tervaniemi&Picton, 2003), it is not yet certain whether familiarizationtooddball stimulus paradigm influencesP300. There are several stimulus factors that influence P300 and practically, in many instances, recording P300 remains a challenge. Although it is proved that complexity of the task influences P300, the effect of familiarity to oddball paradigm on P300 is not yet studied. Considering the existing evidence for repetitive induced suppression in the cortex and the reduction in P300 amplitude with the increase in the number of sweeps by beyond 60, one can speculate the familiarity with oddball paradigm will have an influence on P300. Therefore, the present study aims to systematically study effect of familiarizationto oddball paradigm on P300.

We hypothesize that characteristics of P300 would be significantly affected withfamiliarization. If P300 is primarily triggered by the novelty of the stimulus, considering that the cortical responses show repetition induced suppression, P300 shall be poorer in trained and experienced participants. In such case, one should recruit naïve participants in P300 experiments for good recordings and in turn help in standardizing the recording protocols of P300. The findings of the studywould also help shed light on which among the familiar and novel auditory stimulus is more beneficial in triggering P300 elicitation thereby be pivotal in designing auditory training activities and validation procedures in the future. As a secondary purpose, it was also of interest to study working memory as an interacting variable with the effects of familiarization.

1.2 Aim of the Study

To study the effect familiarization to oddball stimulus paradigm on P300.

1.3 Objectives of the Study

1. To compare the latency, amplitude and area of P300 before and after familiarization to oddball stimulus paradigm

2. To study the effect of working memory on familiarization related differences in P300, if any

1.4 Null Hypothesis of the study:

1. There is no significant difference between experienced and naive individuals in the latency, amplitude and area of P300 before and after familiarization to oddball stimulus paradigm

3. There is no significant effect of working memory on familiarization related differences in P300, if any

Chapter 2

REVIEW OF LITERATURE

The purpose of this study was to shed more light into the current understanding of the dynamics of P300. With the aim of exploring the possibility of familiarity of the odd-ball paradigm posing as a factor affecting P300, this review of literature is directed to have a clear picture of the extent of vulnerability of P300 responses to various conditions.

P300 is an event-related response that is majorly dependent on participant attention to certain auditory stimuli and it is an endogenous response (Polich, 2007). The P3 wave is evoked by a task known as the **odd-ball paradigm**. During this task a series of one type of frequent stimuli (standard stimulus) is presented along with a different of non-frequent (target) stimulus (Squires, 1976). The task of the experimental subject is to react to the presence of target stimulus by a given motor response. If person attends to stimuli, P300 is produced. It is essentially a component within an extended auditory late response time frame.

P300 was first described by Sutton in 1965 as a cognitive evoked response. It is a response with about 15 microvolt amplitude, and with positive deflection from the baseline EEG response. It has a latency between 250 and 400ms after the presentation of response eliciting stimulus (Angeles, Price & Smith, 1974). Virtually, any sensory modality can be used to elicit the response. In descending order of clinical use these are: auditory, visual, somato-sensory, olfactory or even taste stimulation (Ravden&Polich,1999). The shape and latency of the P3 wave differs with each modality. For example, in auditory stimulation, the latency is shorter than in visual stimulation (Katayama &Polich, 1999). This indicates that the sources generating the P3 wave differ and depend on the stimulus modality.

Auditorily P300 can be elicited during passive listening condition which is known as P300a while P300b is recorded during active listening. This requires that the subject pays attention to the infrequent stimulus (Polich, 2007). The P300 response has contributions from different regions of the cerebral hemispheres namely, auditory cortex (Kileny & Robertson, 1985), hippocampus and associated brain structures (Okada et al., 1983) and frontal cortex (Courchesne, 1978).

P300 has applications in assessing the cognitive functions in neurocognitive disorders. P300 has been used for diagnosis of several disorders such as epileptic patients (Resolução et al., 2010), speech processing in children (Henkin, Tetin-Schneider, Hildesheimer & Kishon-Rabin, 2008), Alzheimers(Olichney & Hillert, 2004), Schizophrenia (Heidrich & Strik, 1997), traumatic brain injuries (Lew, Slimp, Price, Massagli & Robinson, 2004). Mullis, Holcomb, Diner and Dykman (1985) suggested that the latency of P300 is directly related to speed of information processing and CAPD children have longer latency of P300 response.

P300 has also been used as an index of neural plasticity. Auditory training causes both long-term and short-term plasticity changes which can be reflected in the P3a and P3b responses (Uther, Kujala, Huotilainen, Shtyrov&Näätänen, 2006). Kubo et al. (2001) recorded P300 and measured word recognition scores in post lingually deaf adult before cochlear implantation. After 1 month, P300 and word recognition was checked and it was concluded that there was an increase in word recognition and decrease in P300 latency was noted. Azzam and Hassan (2010) conducted a study to tap neural plasticity changes in children with auditory processing disorder using P300. Children were auditorily trained for auditory memory, auditory temporal processing and auditory attention and they reported that amplitude of P300 improved with training.

Crummer, Walton, Wayman, Hantz and Frisina (1994) compared P300 responses between adult musicians and non-musicians. They reported that amplitude and latency of the P3 component varied systematically as a function of musical experience. Levett and Martin (1992) presented complex musical stimuli to two groups, musicians and non-musicians. Familiar music context was given which influenced familiar context-updating process and elicitation of P300. They recorded P300 for ongoing musical context and found larger amplitude in musicians than non-musicians. These findings were attributed to the use of additional processing to a greater extent by musicians than the non-musicians because of experience. Caldwell and Riby (2007) recorded pre-attentive potentials and P300. Results indicated that short and long-term music benefits on both conscious and unconscious cognitive processes. Trainor, Desjardins and Rockel (1999) studied the ability to perceive sounds and correctly categorize them within a musical scale in musicians and non-musicians. In musicians, largest frontal P3a (attention) and P3b was observed. The above-mentioned studies show that long term and short-term plasticity changes can be reflected in P300 responses.

2.1 Factors affecting P300

The factors that affect P300 are subject related and stimulus related. Understanding the factors affecting P300 is vital as it helps one to optimize P300 recording in order to get robust responses. It will also enable to eliminate extraneous variables and control the possible influencing factors while designing a P300 study.

Understanding subject related factors will enable a researcher to recruit participants efficiently.

2.1.1. Subject Related Variables

There is relatively less normative data on the P300 response in children. Barajas (1990) reported that the P300 latency has the shortest value at 18-24 years of age and then increases consequently. Buchwald (1990) reported similar findings stating that P300 reach adult value at 17 years of age. McPherson, Tures and Starr (1989) reported that P300 is not fully developed till 5 years and after 5 years latency consequently decreases with age, and then after 50 years of age it increases.

Morita, Morita, Yamamoto, Waseda and Maeda (2001) reported greater amplitude and shorter latency for females than males over the age of 15 years. However Polich (1986) found no significant effect between males and females in latency as well as amplitude of P3 wave.

Alexander and Polich (1997) reported larger P300 amplitude for left handed individuals at Fz, right handed subjects at posterior sites, shorter latency for left vs. right handed subjects. Witelson (1992) reported that possible explanations might include larger corpus callosum in left-handed subjects, differences in skull thickness and attention. The study conducted by (Hong et al., 2013) also found that P300 latency was shorter for left handed individuals.

Begleiter, Porjesz, Chou and Aunon (1983) reported that P300 amplitude increases when the monetary value is attached to correct identification of the target stimuli. The P300 amplitude was noted to be better for motivational instructions than that of neutral ones (Johnson, 1986). and clinical populations, such as patients with schizophrenia (Louzã, Maurer & Neuhauser, 1992)

Lorist, Snel, Kok and Mulder (1994) conducted a study in which they checked the effect of caffeine on P300 using visual stimuli. Results showed reduction in amplitude of P300 and prolongation of peak latency. Lukas studied the effect of alcohol intake on P300 and reported amplitude reductions.

P300 is also influenced by the stare of arousal. Cote (2002) recorded P300 with Fz electrode sites. Responses were absent in stage I and II. Amplitude of P300 decreases and latency increases during the transition from alert awake state to drowsiness and to sleep stage I (Koshino et al., 1993).

2.1.2. Influence of Stimulus Related Variables on P300

Stimulus modality and type:As mentioned earlier in this chapter, to evoke P300 response we can use any sensory modality. When P300 is elicited in the auditory modality, P300 the amplitude and latency of P300 differs based on stimulus used. A variety of auditory stimuli can be used to elicit P300. Picton et al. (1992) reported that the P300 evoked by visual stimulus was delayed by approximately 90ms than that of auditory stimulus which was explained by the difference in the transmission time to the cortex. Authors also reported that P300 component evoked by somato-sensory signal was delayed and larger than auditory or visual stimuli. The target elicits a large positive potential which has a peak latency of 400ms for visual stimuli in young adults (Johnson, 1993; Polich, 2004). Tones, speech sounds such as stop consonants or words and musical segments can be used to elicit P300. Bastuji (1995) reported that measurement of P300 is enhanced or facilitated by first familiarizing the subjects to rare speech stimuli (Bastuji 1995).

Stimulus intensity*:* P300 wave amplitude increases and latency decreases as stimulus intensity increases for both standard and target stimuli used for recording. Vesco, Bone, Ryan and Polich (1993) found that at low intensity levels P300 waveforms showed long latency and reduced amplitude. On the contrary, Papanicolaou, Loring, Raz and

Eisenberg (1985) reported reduction of intensity from 65dB to 15dB made difference in the latency of P300 response but the amplitude of the response remained the same.

Probability of stimulus:Probability of occurrence for the standard and the target stimuli affects P300 response characteristics. Within certain limits, amplitude of the P300 response decreases as the probability of the target stimulus increases (Johnson & Donchin, 1977), whereas the effect of target stimulus probability on P300 latency is minimal (Polich & Bondurant, 1997). However, there is little change in the P300 response when probability of the target stimulus is decreased below 20 percentage (0.20). Given this limitation in the effect of decreased probability, and the increase in test time associated with signal averaging of a response for very target stimuli, the probability in P300 measurement is usually 80 percent for standard and 20 percent for target stimuli.

Number of Sweeps:Repetition suppression is a learning phenomenon in which repetitions of the same stimulus result in diminished brain activity (Knoth et al., 2018). This phenomenon is attributed largely to automatic processes in sensory neurons. Summerfield,Trittschuh, Mont, Mesulam and Egner (2008) reported that manipulating the likelihood of stimulus repetition, repetition suppression in the human brain will reduce when stimulus repetitions were unexpected or improbable. They report that P300 responses are affected by the probability of the stimulus. More expected the stimuli, more will be the repetition suppression and thus affecting the P300 responses. If the predictability of the deviant stimulus is less, repetition induced suppression will also be less.

P300 has been reported to be influenced by the number of sweeps and the probability of the deviant stimuli. Dietrich, Hu and Rosenfeld (2014) used 33, 66 and 100 sweeps to record P300 and they reported that there was actually a trend favoring the least trial numbers. They concluded that 33 sweep averages were sufficient to allow detection of concealed information and as the number of sweeps increased, P300 deteriorated.

Target to target interval: The amplitude of P300 responses increases as the number of frequent stimuli (standard) increases between two infrequent stimulus (target). The target to target interval of 6 to 8 seconds or greater eliminate probability effects (Polich, 1990). A study was done by Gonsalvez and Polich (2002) in which they altered the number of preceding standard stimuli (0, 1, 2, 3) and inter-stimulus interval (1, 2, 4s). They used auditory and visual stimulus for eliciting the P300 response. The results revealed betterment of P300 amplitude with increase in the length of standard auditory/visual stimulus when ISI was constant. It was also noted that the latency of response also became shorter as the standard stimulus length increased. The latency was shorter in case of auditory stimulus than that of visual.

Task of the subject:Tasks given to the subject can be active or passive. In case of passive condition, the client will be asked not to pay attention to the stimulus while in active tasks the client will be asked to selectively attend to the target stimulus (infrequent). Bennington and Polich (1999) compared the effect of passive and active task on P300 for auditory and visual stimuli and it was found that P300 amplitude was larger in active condition than that of passive condition. The amplitude of P300 decreased with repeated stimulation during passive discrimination of standard and target stimuli (Katayama & Polich, 1998).

Task Difficulty:There is considerable evidence that P300 latency becomes longer and amplitude smaller as the difficulty of the listening task increases (Katayama & Polich, 1998).When the standard and the target signals are similar, reaction time and P300 latency are prolonged and the response is less robust. Highly novel target signals produce larger responses with short latency, consistent with shorter evaluation time required to determine that the target signal was different than the standard signal (Ritter et al., 1982). Polich and Comerchero (2003) also found similar results i.e., easy task experiments elicits larger amplitude and reduce peak latency of P300.

From the brief review of literature on the factors affecting P300, it is inevitable to conclude that though P300 has several applications, it is vulnerable to a number of subject and stimulus related factors, because of which, one has to be cautious in selecting participants and stimulus for a study. One has to be cautious in making clinical interpretations based on P300 responses, since it is affected by myriads of subject variables.

2.2. P300 and Working Memory

Generation of P300 contains the process of attention, auditory discrimination, memory and semantic expectancy (Picton & Hillyard, 1974). Neuroinhibition is suggested as an overarching theoretical mechanism for P300, which is elicited when stimulus detection engages memory operations (Polich, 2007).

The amplitude and latency of P300 has been shown to be related to working memory of an individual. Nittono, Nageishi, Nakajima and Ullsperger (1999) assessed working memory capacity using a reading span test and found that the participants with high reading span test produced larger P300s than did those with low reading span in the reading task. It had been suggested that individual differences in working memory capacity would affect initial stages of information processing as early as 300 ms after stimulus onset.

Walto and Frisina (1992) measured P300 for musicians without absolute pitch, musician with absolute pitch, and non-musician. The tasks were two interval discrimination task and simple two-note contour task and difficult interval-size discrimination task. Absolute pitch ability reduces the amplitude and prolong the latency, or eliminate P3 altogether. It was inferred that P300 requires the use of long-term memory strategy involved in the correct discrimination task rather than performing the task by updating working memory each time a target occurs.

Hirose (2002) recorded a P300 in absolute pitch (AP) possessors and non-AP possessors. Study mentioned priory, demonstrated that AP possessors did not appear to employ working memory during auditory oddball tasks because they have a fixed tonal template in their memories. However, the present findings showed that the AP possessors exhibited similar P300 as the non-AP possessors and did update the tonal context in the 16 auditory oddball tasks. The findings of this study suggest that individuals employ working memory appropriately according to the difficulty of the auditory tasks and the AP possessors do not always refer to the fixed tonal template in their memories when executing the oddball tasks.

These studies suggest that P300 is a complex response that is also affected by cognitive processes such as working memory. P300 seems to be vulnerable to the dynamics of working memory also.

Chapter 3

METHOD

The aim of the study was to determine the effects of familiarity of the odd ball paradigm on P300. As a secondary purpose, it was also of interest to study working memory as an interacting variable with the effects of odd ball paradigm familiarization.

The null hypothesis of the study was that there is no significant difference between experienced and naive individuals in their P300. To test the hypothesis, a quasi-experimental research design was employed. Baseline P300 recordings were obtained in all the participants. The experimental groups were systematically exposed to the odd ball paradigm and thereafter, P300 responses were recorded again to examine the effects of familiarization.Working memory was assessed and accordingly the participants in the experimental group were classified as high working memory and low working memory groups.

3.1. Participants

A total of thirty participants in the age range of 18 to 20 years were selected for the study. The participants had normal hearing sensitivity (pure tone thresholds within 15dBHL at octave frequencies between 250Hz & 8000Hz), normal middle ear status (as tested in immittance evaluation) and normal outer hair cell functioning (TEOAE amplitudes of greater than 6dBSPL at octave frequencies between 1kHz & 6kHz). A detailed case history was taken to ensure that they did not have any past or present history of otological or neurological dysfunctions. Screening test for Auditory processing (STAP) was administered to screen out Auditory Processing Disorders.The participants of the study were not familiar with the concept of odd ball stimulus paradigm and had not been participants for P300 recording earlier to this study. A written consent was taken from all the participants for their willingness to participate in the study.

The thirty qualifying participants were randomly assigned to three groups with each group consisting of ten participants;Experimental group I (High working memory group), Experimental group II (low working memory group) and the control group. All of the participants had completed secondary education and were in the first year of a graduate program at AIISH. Students in the first year of the graduate program were incorporated in the study to ensure that none of the participants were familiar with the concept of odd ball paradigm.

3.2. Stimuli to Record P300 and for Familiarization

The stimuli used to record P300 were different from those used for familiarizing the participants to oddball paradigm. A pilot study was conducted to choose the pair od stimuli that elicits god P300 in most individuals. Stop consonants were preferred for the pilot considering that they elicit good late latency responses (LLRs). Syllables /pa/, /ta/, /ka/, /ba/, /da/, /ga/, /ja/ and /dha/ (belonging to Kannada phonetic inventory) were recorded from an adult male who was a native Kannada speaker. Adobe Audition (Version 3) was used for the purpose and the recording was done in standard settings. LLRs were recorded for all of these syllables on three different individuals. Among them, syllables /pa/, /ta/ and /ka/ were found to have robust LLRs. P300s were then recorded from another set of three individuals using all possible combinations of /pa/, /ta/ and /ka/ as frequent and infrequent stimuli (/pa/- /ta/, /ta/-/pa/, /pa/-/ka/,/ka/-/pa/, /ta/-/ka/ and /ka/-

/ta/. The recordings showed that P300s were best when /pa/ was frequent stimulus and /ta/ was infrequent stimulus on all the individuals. Therefore, /pa/- /ta/ was selected as the test stimuli.

The other syllables, /ba/, /da/, /ga/, /ja/ and /dha/ were used to synthesize the stimuli for familiarization to odd ball paradigm. Stimulus pairs used for familiarization were /ba/-/da/, /da/-/ga/, /dha/-/ba/, /ga/-/ja/ and /ja/-/tha/, where the former syllables in the pair were the frequents and the latter syllables were the infrequents in all of the pairs. There was no specific reason to assign the frequent and infrequent stimuli in case of the stimuli used for familiarization.

To record P300, syllable /pa/ was used as the frequent stimulus and /ta/ was used as the infrequent stimulus. Figure 3.1 (a) and (b) shows waveform of the syllables /pa/ and /ta/ respectively. Table 3.1 shows the stimulus characteristics of /pa/ and /ta/.

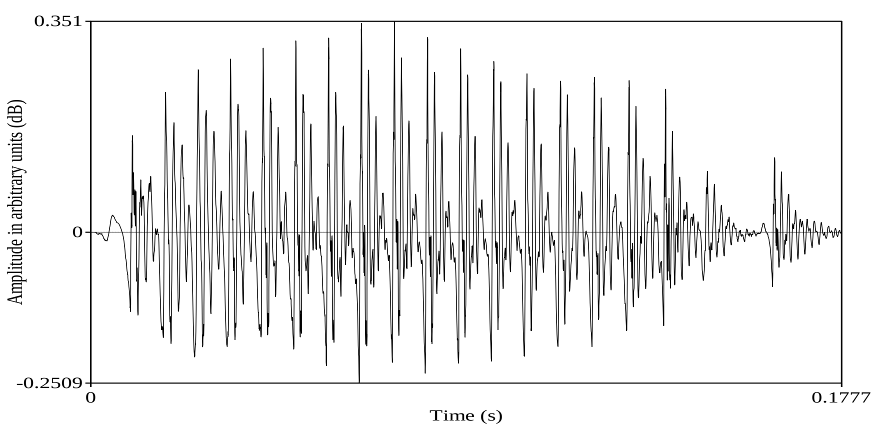


Figure 3.1(a): Waveform of the syllable /pa/ used in the present study.

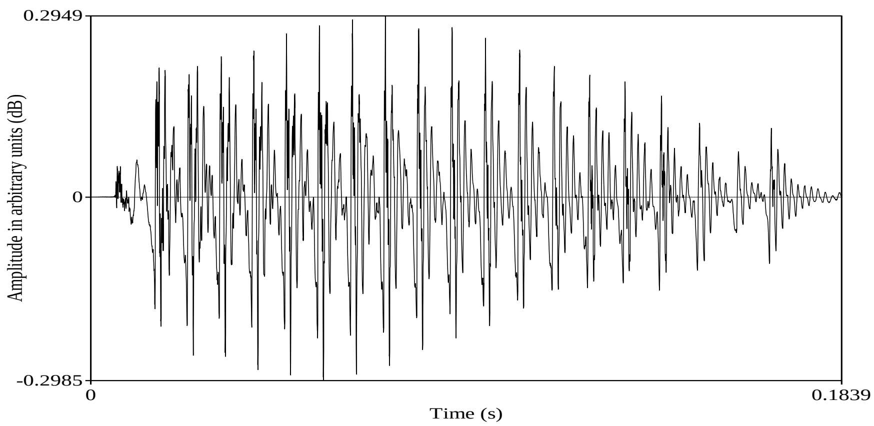


Figure 3.1 (b): Waveform of the syllable /ta/ used in the present study.

Table 3.1: Spectral and temporal characteristics of /pa/ and /ta/syllables used in the present study

Parameter	**/pa/**	**/ta/**
F0	124.8 Hz	120 Hz
F1	604.22	622.87 Hz
F2	1158.95	1337.07 Hz
VOT	17ms	12ms
Duration	177ms	183ms

3.3. Test Environment

All tests were carried out in a sound treated room with noise levels within the permissible limits (ANSI S3.1-1999). The rooms used for AEP recording were also electrically shielded.

3.4. Test Procedure

3.4.1 Preliminary Audiological Evaluations

A preliminary audiological evaluation was done to check if the participant fulfils all the inclusion criteria. Pure-tone thresholds were obtained at octave frequencies between 250 Hz to 8000 Hz, using a calibrated dual channel audiometer (GSI-61 with TDH 49 Earphones with MX-41/AR ear cushions). Speech recognition thresholds, speech identification scores and uncomfortable level of the two ears was also obtained monaurally.

Immittance evaluation was carried out using a calibrated GSI Tympstar immittance meter. Tympanometry was obtained by varying the pressure within the ear canal from +200 to -400 daPa. Compensated static admittance and peak pressure were noted down to interpret the tympanogram. Ipsilateral and contralateral acoustic reflexes thresholds were measured for 500, 1000, 2000 and 4000Hz. TEOAEs were obtained using the standard clinical protocol available in ILO292 Echoport plus. Clicks were presented in the non-linear stimulus mode, at around 80dBSPL. Amplitude of TEOAEs at octave and midoctave frequencies between 1kHz and 6kHz were noted down.

3.4.2 Experimental Procedure

The experimental procedure included 4 phases:

Phase I - Administering WM test and assignment to groups

Phase II - Baseline Recordings of P300

Phase III -Exposure to the oddball stimulus paradigm in experimental groups

Phase IV - Post exposure recordings of P300

Phase I - Administering WM tests and assignment to groups: Working memory tests were administered in all the thirty participants. Participants were seated comfortably in an acoustically treated room and instructions were given. Working memory assessment was carried out using digit span of Smriti-Shravan software (Kumar &Maruthy, 2016). Based on the results of working memory test (Auditory digit span), twenty participants (ten each) were divided into good and poor working memory groups based on the normative established by Jain and Kumar (2017). The Lower and upper bound cut offs based on the 95% confidence intervals in their study was 5.32 and 6.01. Therefore, individuals with scores above 6.01 were classified as individuals with good working memory whereas individuals with scores below 5.32 were classified as individuals with poor working memory. Working memory task was carried out using a Dell laptop with Intel core i7 processor. A headphone was used for the delivery of auditory stimulus.

Auditory digit span (backward phase): Cluster of digits were presented in random order. The participant’s task was to reproduce them in the backward order in backward phase. Total score was calculated based on the digits the participant could successfully recall. The test consisted of a total of 6 reversals, wherein the first two reversals were rejected and the mean of the midpoints of the last 4 reversals were taken as the final score.

Phase II - Baseline Recordings of P300: Two recordings of P300 were taken within a session. Electrodes were removed and replaced after the first recording with a break of 20 to 30mins to eliminate fatigue. An Intelligent Hearing System (IHS) AEP system with smart EP was used for recording and analyzing P300.

Participants were explained about the test procedure and also the tasks to be performed. The participants were then seated comfortably and electrodes were placed in accordance with the international 10-20 system (Jasper, 1958). Participants were then instructed to relax and remain alert throughout the testing, to keep their eyes open and to fixate their vision to one spot. They were also asked to make a mental count of infrequent stimulus (ta) in series of frequent stimulus (pa). At the end of the recording they were asked to report the number of stimuli counted. This was done in order to ensure that the participants were attending to the stimuli.

Additionally, an LLR was recorded for the deviant/infrequent stimuli (/ta/) using the same protocol that was used to record the P300 response but with /ta/ presented at 100% probability. Table 3.2 gives the stimulus and acquisition parameters used to record P300.

Phase III - Exposure to the oddball stimulus paradigm in experimental groups: Only the participants in experimental groups were subjected to exposure to the oddball paradigm. Maximum of 5 sessions of familiarization was given. Each session of 15 minutes was held over a span of one week. The stimuli were presented at the comfortable level of each listener using a Dell laptop with Intel core i7 processor. A headphone was used for the delivery of auditory stimuli. The individuals were asked to listen to the odd ball paradigm and write down the number of times the infrequent stimuli appear. Writing down the number of times infrequent stimuli appears ensured that the individuals paid attention to the stimuli. The total count given by the participant was matched with the total number of infrequents presented. The combination of syllables used was different in each session and was different from the one used for recording P300. Stimuli used for familiarization were /ba/-/da/, /da/-/ga/, /dha/-/ba/, /ga/-/ja/ and /ja/-/tha/

Table 3.2: Stimulus parameters and acquisition parameters used to record P300

Stimulus Parameters	
Stimulus	Speech sounds (frequent: /pa/ and infrequent: /ta/)
Standard to deviant ratio	4 to 1 (80:20)
Transducer	Insert phones
Ear	Binaural
Intensity	70 dB HL
Repetition rate	1.1/s
Acquisition Parameters	
Electrode locations	Cz – Non-inverting Nose tip - Inverting (Reference) Fpz- Ground
Others	Ocular electrodes (above and below the eye)

Total number of trials	80 deviants
Analysis time	-100 ms to 500 ms
Filter setting	1-30 Hz
Amplification	1,00,000

Phase IV - Post exposure recording of P300: Two more recordings of P300 were elicited after the 5 session of exposure to oddball paradigm in the two experimental groups. In the control group, two more recordings were elicited with a gap of 5 days from the initial recording without exposing them to the odd ball paradigm. The protocol used to record P300 in this phase was same as that of Phase II.

3.5 Response Analysis

P300 responses were visually analyzed by comparing the deviant response of the P300 protocol and the LLR recorded for /ta/. Three experienced audiologists independently analyzed the response and only if the marked responses showed good agreement among the three, response parameters were noted down. Response was analyzed for its peak latency, onset latency, offset latency, peak amplitude and the area.

Chapter 4

RESULTS

This study was done to explore the possibility of the familiarization to the odd ball paradigm posing as a factor affecting P300. The secondary objective was to test the effect of working memory as an interacting variable. The dependent variables considered were onset latency, peak latency, offset latency, peak amplitude and the area of P300. The independent variables were familiarization to oddball paradigm and working memory. Shapiro-Wilk test of normality revealed normal distribution of the variables. Therefore, a parametric test, namely repeated measures ANOVA was used to analyze the data. The results obtained are reported under the following headings.

1) Effect of familiarization to oddball paradigm on latency of P300
2) Effect of familiarization to oddball paradigm on amplitude of P300
3) Effect of familiarization to oddball paradigm on area of P300
4) Group as an interacting variable on the effects of familiarization
5) Comparison of P300 between Good and Poor WM groups

4.1 Effect of Familiarization to Oddball Paradigm on Latency of P300

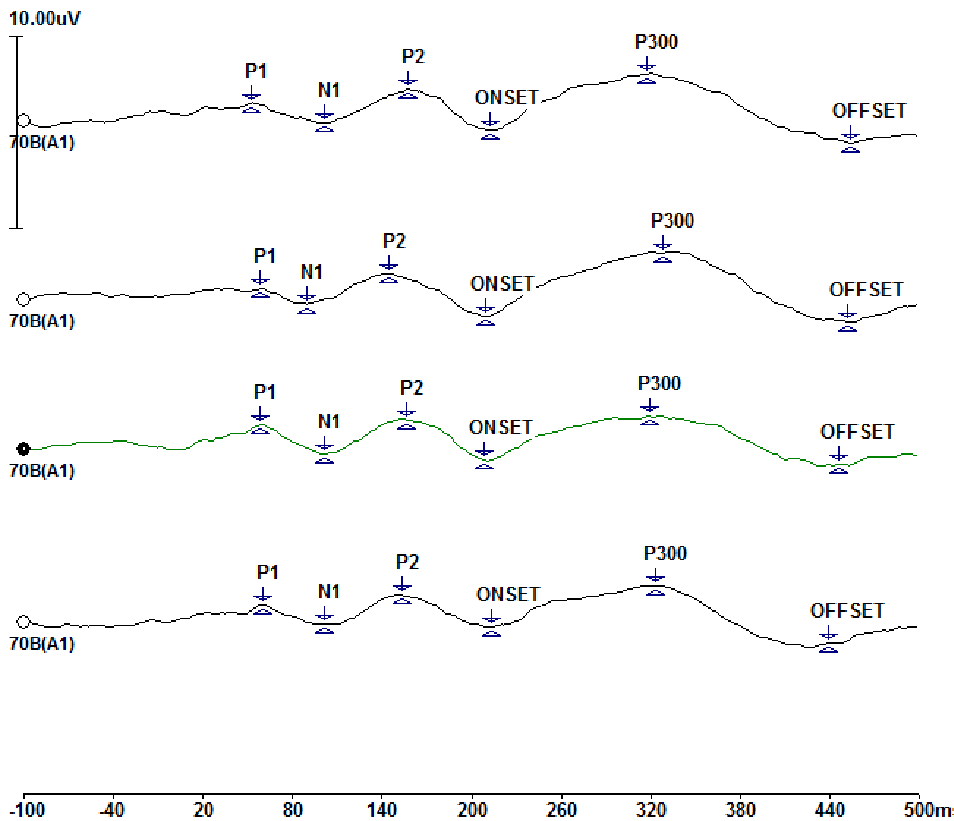
Table 4.1 gives the mean and standard deviation of latency measures of P300 (onset, offset & peak latency) across the four sessions in control and experimental groups (both good & poor WM groups). The mean onset latency was prolonged in session 4 compared to the earlier sessions in all the 3 groups. On the other hand, peak latency and offset latency were shorter in the sessions 3 and 4 compared to sessions 1 and 2. This was true in all the 3 groups.

However, there was no significant main effect of sesssion on onset latency [$F(3,27) = 1.751$, $p>0.05$], peak latency [$F(3,27) = 2.373$, $p>0.05$] and offset latency [$F(3,27) = 0.786$, $p>0.05$] of P300, as on repeated measures ANOVA.

Table 4.1:Mean and standard deviation of latency measures of P300 (onset, peak and offset latency) across four sessions in control group and the two experimental groups

Latency Parameter	**Group**	**Sessions**			
		1	**2**	**3**	**4**
Onset (ms)	Control	240.6 25.82	236.0 21.79	240.0 45.16	266.8 69.64
	Good WM	229.2 21.64	223.3 31.97	225.2 28.93	231.7 30.19
	Poor WM	229.18 32.60	228.9 25.27	237.8 50.46	245.9 40.03
Offset (ms)	Control	430.4 22.6	449.4 23.31	441.6 20.84	433.1 43.95
	Good WM	441.5 27.48	430.7 22.2	427.7 27.03	432.2 25.78
	Peak WM	465.9 26.61	450.9 21.69	446.9 21.67	448.0 13.50
Peak (ms)	Control	340.1 13.35	325 25.7	324.8 46.42	336.3 27.15
	Good WM	326.4 37.48	330.4 31.23	311.4 35.93	297.8 34.04
	Peak WM	349.8 11.75	338.1 26.74	325.5 40.49	332.6 43.50

Figure 4.1 shows the grand averaged P300 (averaged across 10 participants) in the four sessions of recording in the good working memory group. As can be observed from the figure, latency remained similar across all the four sessions. Similarly, comparable grand averaged waves across the four sessions were seen in the other two study groups also.



Grand averaged P300 (averaged across 10 participants) in the four sessions of recording, in the good working memory group.

4.2 Effect of Familiarization to Oddball Paradigm on Amplitude of P300

Table 4.2 gives the mean and standard deviation of peak amplitude of P300 across the four sessions in control and experimental groups (both good & poor WM groups). Mean peak amplitude of P300 successively reduced with session in the control group. No such trend was observable in the experimental groups.

Results of repeated measures ANOVA showed that there is no significant main effect of session on peak amplitude of P300 [F (3,27) =2.0723, p>0.05]. Equivalent amplitudes in the grand averaged waves across the 4 sessions can be seen in Figure 4.1.

Table 4.2:Mean and standard deviation of peak amplitude (μV) of P300 across four sessions in control and the two experimental groups

Group	**Sessions**			
	1	**2**	**3**	**4**
Control	7.25	6.07	4.67	4.62
	2.57	2.64	1.28	1.34
Good WM	7.91	6.84	7.94	7.31
	2.59	3.43	3.16	2.69
Poor WM	7.68	7.77	7.39	6.85
	3.85	3.26	4.04	2.57

4.3 Effect of Familiarization to Oddball Paradigm on Area of P300

Table 4.3 gives the mean and standard deviation of area of P300 across the four sessions in control and experimental groups (both good & poor WM groups). Mean area of P300 reduced in session 3 and 4 compared to 1 and 2 in the control group. On the other hand mean area successively reduced in with sessions in poor WM group. No such trend was observable in the good WM group.

Results of repeated measures ANOVA showed that there is no significant main effect of session on area of P300 [F (3, 27) = 2.362, p>0.05].

*Table 4.3:Mean and standard deviation of area (ms*µV) of P300 across four sessions in control and the two experimental groups*

	Sessions			
Group	**1**	**2**	**3**	**4**
Control	417.52	617.38	357.18	371.08
	204.26	276.5	208.8	178.35
Good WM	643.58	623.05	489.77	651.00
	220.77	247.05	251.1	301.95
Poor WM	793.66	679.96	628.78	473.31
	542.21	350.96	350.03	231.84

4.4.Group as an Interacting Variable on the Effects of Familiarization

While the effect of session on parameters of P300 was being assessed in repeated measures ANOVA, group was fed as the between-subject factor. Results showed that there was no significant interaction between session and group. This was true for all the parameters of P300; onset latency [F (6, 27) = 0.359, p>0.05], peak latency [F (6, 27) =

0.966, p>0.05], offset latency [F (6, 27) = 1.211, p>0.05], peak amplitude [F (6, 27) = 1.146, p>0.05] and area [F (6, 27) = 1.281, p>0.05].

4.5.Comparison of P300 between Good and Poor WM groups

The mean and standard deviation of latency, amplitude and area of P300 was compared between good and poor working memory groups can be found in Table 4.1, 4.2. and 4.3. The two groups were compared for their P300 recorded in session 1. Mean onset latency was similar, while the mean peak and offset latency were prolonged in poor WM group compared to good WM group. Mean amplitude was lower and area was higher in poor WM compared to good WM group. An Independent sample t-test was used to compare between the two groups and the results (Table 4.4) revealed that none of the mean differences were statistically significant.

Table 4.4:Results of Independent sample t-test comparing Good WM and Poor WM for their P300 recorded in session 1

Parameter	**T**	***p***	***d.f***
Onset Latency (ms)	-0.94	0.40	18
Offset Latency (ms)	-2.01	0.59	18
Peak Latency (ms)	-1.88	0.54	18
Amplitude (µV)	-0.81	0.17	18
Area (ms*µV)	0.15	0.25	18

Chapter 5

DISCUSSION

P300 has applications in assessing the cognitive functions in neurocognitive disorders (Olichney & Hillert, 2004) and has been used for diagnosis of several disorders (Resolução et al., 2010; Lew, Slimp, Price, Massagli & Robinson, 2004). It has also been used as an index of neural plasticity (Kujala, Huotilainen, Shtyrov&Näätänen, 2006). However, it is a complex event related potential whose responses are vulnerable to changes due to a variety of subject and stimulus related factors. In many instances recording P300 still remains a challenge. The present study aimed to explore the possibility of familiarity to odd ball paradigm posing as a factor affecting P300. The findings of this study would shed more light in understanding the dynamics of P300. Such an understanding would benefit particularly the researchers while recruiting the participants for a P300 study.

Familiarity of a complex environmental sound influences several stages of auditory processing outside the focus of attention (Kirmse, Jacobsen, &Schröger, 2009). Kirmse, et al. (2009) studied the influence of familiarity of an environmental sound on sound processing outside the focus of attention and found that the familiar sound elicited a frontocentrally enhanced P2 and an additional P250. Dietrich, Hu and Rosenfeld (2014) found that no more than 33 sweep averages is adequate to allow accurate detection of concealed information. The authors compared 33, 66 and 100 sweep averages in this study. These findings do indeed lead one to assume that familiarization to the oddball paradigm could have have an effect on P300 responses.

However, in the present study we did not find the influence of familiarity to oddball paradigm on P300. If familiarity to oddball paradigm did have an effect on P300, there should have been a significant difference in the P300 parameters in the experimental groups between pre and post exposure sessions. But there were no significant differences in amplitude, latency and area measures post familiarization to oddball paradigm in the experimental groups. Furthermore, there was no significant interaction of group and session which supports that familiarity did not have an influence on P300. In the present study, control group was not subjected to 5 sessions of exposure to oddball paradigm while experimental groups were put through these sessions.

It is important to note that, in this study all of the stimuli used for familiarization consisted of different syllable pairs and the probability of the occurrence of the deviant stimuli was 20% in all the stimuli used. Probability of occurrence for the standard and the target stimuli affects P300 response characteristics. Within certain limits, amplitude of the P300 response decreases as the probability of the target stimulus increases (Johnson & Donchin, 1977), whereas the effect of target stimulus probability on P300 latency is minimal (Polich & Bondurant, 1997).

The syllable pair used for recording of P300 was different from those used for familiarization. Thus, the experimental groups were not familiarized to the acoustics of the stimulus used for recording but only to the phenomena of odd ball paradigm. The inferences drawn from the present study should take this issue into consideration. If the same stimuli were used for familiarization, the results obtained might have been different. The occurrence of the deviant stimuli was random in all the materials used for familiarization. Walto and Frisina (1992) reported that individuals can use information stored in the long-term memory which can be involved in the correct discrimination rather than performing the task by updating working memory each time a target occurs, which in turn can cause poor P300 responses.

Hirose (2002) suggested that individuals employ working memory appropriately according to the difficulty of the auditory tasks and individuals do not always refer to the fixed tonal template in their memories when executing the oddball tasks. Extrapolating from the findings of these studies we speculate that the random nature of the odd ball paradigm did not create a fixture or a template in the long-term memory storage thus leaving the task of discriminating the deviant, which employs working memory, unaffected. It can be argued that the random nature of the odd ball task leaves less space for repetition induced suppression. The different stimulus pairs used for training also would have contributed for the lack of significant difference.

Our findings are in partial consonance with SummerfieldTrittschuh, Mont, Mesulam and Egner (2008) where they report that manipulating the likelihood of stimulus repetition, repetition suppression in the human brain will deteriorate when stimulus repetitions were unexpected or improbable. They reported that P300 responses are affected by the probability of the stimulus. More expected the stimuli, more will be the repetition suppression and thus affecting the P300 responses. If the predictability of the deviant stimulus is less repetition induced suppression will also be less. Familiarizing individuals with the same syllables used for recording P300, possibly would have resulted in repetition induced suppression, due to familiarity of the acoustics of the syllables and not due to familiarization of oddball paradigm.

The two sessions of pre-familiarization and two sessions of post familiarization in all the three groups had no significant difference in their amplitude, latency and area measures. This suggests that P300 has good test-retest reliability. However, one needs to run appropriate statistical tests before making any conclusive remarks on its reliability. Such tests were not done in this study as it was out of the scope of interest to this study.

Furthermore, working memory had no interaction effects on the effect of familiarity in this study. P300, is elicited when stimulus detection engages memory operations (Polich, 2007). Generation of P300 contains the process of attention, auditory discrimination, memory and semantic expectancy (Picton & Hillyard, 1974). Nittono, Nageishi, Nakajima and Ullsperger (1999) assessed working memory capacity using a reading span test and found that the participants with high reading span test produced larger P300s than did those with low reading span in the reading task. They had suggested that individual differences in working memory capacity would affect initial stages of information processing as early as 300 ms after stimulus onset. However, in this study, though the experimental group I- (Good WM) had better mean amplitude and latency values than the experimental group II- (Poor WM) in most sessions, the differences were not significantly different. Whether or not the absence of significant differences was due to a lack of a stringent criteria to demarcate between the groups is debatable. Future studies can attempt to take groups with larger difference in working memory and verify the same.

The studies suggest that P300 is a complex response that is also affected by cognitive processes. Based on the present study it can be concluded that P300 is not affected by the familiarity to the odd ball paradigm. Therefore, researchers can recruit experienced or naïve individuals to record P300. However, one must be careful in generalizing the findings of this study. The inferences made from this study are only for individuals who were exposed to oddball paradigm for a maximum of five sessions lasting 15 minutes each. Further, the stimuli used were difference while recording P300 and for familiarity. P300 responses being affected due to exposure to oddball paradigm to prolonged durations of time than that used in the study may or may not be affected.

Chapter 6

SUMMARY AND CONCLUSIONS

If P300 is primarily triggered by the novelty of the stimulus, considering that the cortical responses show repetition induced suppression, P300 should be poorer in trained and experienced participants. In such case, one should recruit naïve participants in P300 experiments for good recordings and in turn help in standardizing the recording protocols of P300. The present study aimed to explore the possibility of the effect of familiarization to oddball stimulus paradigm posing as a factor affecting P300. The null hypothesis of the study was that there is no significant difference between experienced and naive individuals in their P300.

A quasi-experimental research design was employed. A total of thirty participants in the age range of 18 to 20 years were selected for the study. There were three groups in this study namely a control (n=10) and two experimental groups. The two experimental groups were, one with high working memory (n=10) and one with poor working memory (n=10). Baseline P300 recordings were obtained in all the participants. Working memory was assessed and accordingly the participants in the experimental group were classified as high working memory and low working memory groups. The control group was not familiarized to odd ball paradigm. Whereas, the experimental groups were systematically exposed to the odd ball paradigm and thereafter, P300 responses were recorded again to examine the effects of familiarization. Totally four recordings of P300 were done in each participant.

Repeated measures ANOVA was done to analyse the data. There was no significant main effect of familiarization on amplitude, latency and area measures when tested across all the four sessions. There was no significant interaction between session and group. Independent tests were done to compare the P300 between the high and low working memory groups. There were no significant differences between the groups.

We speculate that the random nature of the odd ball paradigm did not create a fixture or a template in the long-term memory storage thus leaving the task of discriminating the deviant, which employs working memory unaffected. It can be argued that the random nature of the odd ball task leaves less space for repetitive induced suppression. The lack of interaction effects of WM on familiarization effects were probably due to lack of differences of P300 between the two experimental groups.

We, conclude that P300 is not affected by the familiarity to the odd ball paradigm. Therefore, researchers can recruit experienced or naïve individuals to record P300. However, one must be careful in extrapolating the findings of this study, the inferences made from this study are only for individuals who were exposed to oddball paradigm for a maximum of five sessions lasting 15mins each. Studying familiarization effects using prolonged durations of exposure, and varying the probability of occurrence are future directions of research.

References

Alexander, J. E., & Polich, J. (1997). Handedness and P300 from Auditory Stimuli. *Brain and Cognition*, *35*(2), 259–270. http://doi.org/10.1006/brcg.1997.0941

ANSI S3.1. (1999). Maximum Permissible Ambient Noise Levels for Audiometric Test Rooms. American National Standards Institute, S3.1-1999. New York: American National Standards Institute, Inc.

Angeles, L., Price, R. L., & Smith, D. B. D. (1974). The P 3 (00) wave of the averaged evoked potential : *Physiological Psychology*, *2*(3A), 387–391.

Azzam, H., & Hassan, D. (2010). Auditory Brainstem Timing and Cortical Processing in Attention Deficit Hyperactivity Disorder. *Current Psychiatry*, *17*(1), 15–21.

Barajas, J. J. (1990). The effects of age on human P3 latency. *Acta Oto-Laryngologica. Supplementum*,*476*,157–60.Retrievedfromhttp://www.ncbi.nlm.nih.gov/pubmed/2087957.

Bastuji, H., García-Larrea, L., Franc, C., & Mauguière, F. (1995). Brain processing of stimulus deviance during slow-wave and paradoxical sleep: a study of human auditory evoked responses using the oddball paradigm. *Journal of clinical neurophysiology: official publication of the American Electroencephalographic Society*, *12*(2), 155-167.

Begleiter, H., Porjesz, B., Chou, C. L., & Aunon, J. I. (1983). P3 and Stimulus Incentive Value.*Psychophysiology*,*20*(1),95–101.http://doi.org/10.1111/j.1469-8986.1983.tb00909.x

Bennington, J. Y., &Polich, J. (1999). Comparison of P300 from passive and active tasks for auditory and visual stimuli. *International Journal of Psychophysiology*, *34*(2), 171-177.

Besson, M., Faïta, F., & Requin, J. (1994). Brain waves associated with musical differ for musicians and non-musicians. Neuroscience letters, 168(1), 101-105.

Brattico, E., Tervaniemi, M., & Picton, T. W. (2003). Effects of brief discrimination-training on the auditory N1 wave. *Neuroreport*, *14*(18), 2489-2492.

Buchwald, J. S. (1990). Comparison of plasticity in sensory and cognitive processing systems. Clinics in Perinatology, 17(1), 5766. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/ 2318016.

Butcher, J. (1983). P300 as a clinical diagnostic tool: The effects of changes in stimulus frequency and intensity and response mode on P300 [Doctoral dissertation, University of Kansas]. *Dissertation Abstracts International*.

Caldwell, G. N., &Riby, L. M. Event Related Potentials and the Musical Brain: The Effects of Music Preference and Music Training on Pre-attentive Stimulus Recognition (N200) and Memory Updating (P300) Processes

Cote, K. A. (2002). Probing awareness during sleep with the auditory odd-ball paradigm. *International Journal of Psychophysiology*, *46*(3), 227-241.

Courchesne, E. (1978). Neurophysiological correlates of cognitive development: changes in long-latency event-related potentials from childhood to adulthood. *Electroencephalography and Clinical Neurophysiology*, *45*(4), 468–82. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/81749.

Crummer, G. C., Walton, J. P., Wayman, J. W., Hantz, E. C., & Frisina, R. D. (1994). Neural processing of musical timbre by musicians, nonmusicians, and musicians possessing absolute pitch. The Journal of the Acoustical Society of America, 95(5), 2720-2727.

Cycowicz, Y. M., & Friedman, D. (1998). Effect of sound familiarity on the event-related potentials elicited by novel environmental sounds. *Brain and Cognition*, *36*(1), 30-51.

Daneman, M., & Carpenter, P. A. (1980). Individual differences in working memory and reading. *Journal of verbal learning and verbal behavior*, *19*(4), 450-466.

Dietrich, A. B., Hu, X., & Rosenfeld, J. P. (2014). The effects of sweep numbers per average and protocol type on the accuracy of the P300-based concealed information test. *Applied psychophysiology and biofeedback*, *39*(1), 67-73

Duncan-Johnson, C. C., & Donchin, E. (1977). On Quantifying Surprise: The Variation of Event-Related Potentials With Subjective Probability. *Psychophysiology*, *14*(5), 456–467. http://doi.org/10.1111/j.1469-8986.1977.tb01312.x

Eggermont, J. J. (1990). The correlative brain. In *The correlative brain* (pp. 267-281). Springer Berlin Heidelberg.

Gilbert, C. D., Sigman, M., & Crist, R. E. (2001). The neural basis of perceptual learning. *Neuron*, *31*(5), 681-697.

Gonsalvez, C. L., & Polich, J. (2002). P300 amplitude is determined by target-to-target interval. *Psychophysiology*, *39*(3), 388–96. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/12212658.

Heidrich, A., & Strik, W. K. (1997). Auditory P300 topography and neuropsychological test performance: Evidence for left hemispheric dysfunction in schizophrenia. *Biological Psychiatry*, *41*(3), 327–335. http://doi.org/10.1016/S0006-3223(96)00030-3.

Henkin, Y., Tetin-Schneider, S., Hildesheimer, M., & Kishon-Rabin, L. (2008). Cortical neural activity underlying speech perception in postlingual adult cochlear implant recipients. *Audiology and Neurotology*, *14*(1), 39–53.

http://doi.org/10.1159/000153434.

Hirose, H., Kubota, M., Kimura, I., Ohsawa, M., Yumoto, M., & Sakakihara, Y. (2002). People with absolute pitch process tones with producing P300. *Neuroscience letters*, *330*(3), 247-250.

Hong, J. S., Lee, J. H., Yoon, Y. H., Choi, J. H., Shin, J. E., Kim, S. M., & Park, Y. G. (2013). The assessment of reliability of cognitive evoked potential in normal person. *Annals of Rehabilitation Medicine*, *37*(2), 263–268. http://doi.org/10.5535/arm.2013.37.2.263.

Jasper, H. (1958). Report of the committee on methods of clinical examination in electroencephalography. *ElectroencephalogrClinNeurophysiol*, *10*, 370-375.

Jain,C. & Kumar,A.U. (2017) Relationship among physhophysical abilities, speech perception in noise and working memory on individuals with normal hearing sensitivity across different agr groups. Unpublished doctoral thesis submitted to University of Mysuru. All India Institite of Speech and Hearing, Mysuru.

Johnson.R. (2007). On the neural generators of the P300 component of the event-related potential. *Psychophysiology*, *30*(1), 90–97. http://doi.org/10.1111/j.1469-8986.1993.tb03208.x.

Johnson, R. (1986). A triarchic model of P300 amplitude. *Psychophysiology*, *23*(4), 367–84. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/3774922

Johnson, R. (1993). On the neural generators of the P300 component of the event-related potential. *Psychophysiology*, *30*(1), 90-97.

Katayama, J., & Polich, J. (1998). Stimulus context determines P3a and P3b. *Psychophysiology*, *35*(1), 23–33. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/9499703.

Keith, R. W. (1994). N SCAN-A: A test for auditory processing disorders in adolescents and adults.o Title. *Psychological Corporation*.

Kileny, Robertson. (1985). Neurological aspects of infant hearing assessment. *The Journal of Otolaryngology. Supplement*, *14,* 34–9. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/3864991.

Kirmse, U., Jacobsen, T., & Schröger, E. (2009). Familiarity affects environmental sound processing outside the focus of attention: An event-related potential study. *Clinical neurophysiology*, *120*(5), 887-896.

Knoth, I. S., Lajnef, T., Rigoulot, S., Lacourse, K., Vannasing, P., Michaud, J. L., ... & Lippé, S. (2018). Auditory repetition suppression alterations in relation to cognitive functioning in fragile X syndrome: a combined EEG and machine learning approach. *Journal of neurodevelopmental disorders*, *10*(1), 4.

Koshino, Y., Nishio, M., Murata, T., Omori, M., Murata, I., Sakamoto, M., &Isaki, K. (1993). The influence of light drowsiness on the latency and amplitude of P300. *Clinical Electroencephalography*, *24*(3), 110-113.

Kubo, T., Yamamoto, K., Iwaki, T., Matsukawa, M., Doi, K., & Tamura, M. (2001). Significance of auditory evoked responses (EABR and P300) in cochlear implant subjects. *Acta Oto-Laryngologica*, *121*(2), 257–61. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/11349791.

Kumar, A.U., Maruthy, S. ARF Project(2016) Smrithi-Shravan Software. All India Institute of Speech and Hearing.

Levett, C., & Martin, F. (1992). The relationship between complex music stimuli and the late components of the event-related potential. Psychomusicology: A Journal of Research in Music Cognition, 11(2), 125.

Lew, H. L., Slimp, J., Price, R., Massagli, T. L., & Robinson, L. R. (2004). Comparison of speech-evoked v tone-evoked P300 response: implications for predicting outcomes in patients with traumatic brain injury. *American Journal of Physical Medicine & Rehabilitation / Association of Academic Physiatrists*, *78*(4), 367–71. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/10418844.

Lippé, S. (2018). Auditory repetition suppression alterations in relation to cognitive functioning in fragile X syndrome: a combined EEG and machine learning approach. *Journal of neurodevelopmental disorders*, *10*(1), 4.

Lorist, M. M., Snel, J., Kok, A., & Mulder, G. (1994). Influence of caffeine on selective attention in well-rested and fatigued subjects. *Psychophysiology*, *31*(6), 525–34. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/7846213.

Louzã, M. R., Maurer, K., & Neuhauser, B. (1992). Functional relationship between brain regions in schizophrenia evaluated with Pearson's correlation between event-related potentials. *Electromyography and Clinical Neurophysiology*, *32*(12), 611–4. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/1493775.

Lukas, S. E., Mendelson, J. H., Kouri, E., Bolduc, M., & Amass, L. (1990). Ethanol-induced alterations in EEG alpha activity and apparent source of the auditory P300 evoked response potential. *Alcohol (Fayetteville, N.Y.)*, *7*(5), 471–7. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/2222851.

McPherson, D. L., Tures, C., & Starr, A. (1989). Binaural interaction of the auditory brain-stem potentials and middle latency auditory evoked potentials in infants and adults. *Electroencephalography and Clinical Neurophysiology/Evoked Potentials Section*, *74*(2), 124–130. http://doi.org/10.1016/0168-5597(89)90017-8.

Morita, Y., Morita, K., Yamamoto, M., Waseda, Y., & Maeda, H. (2001). Effects of facial affect recognition on the auditory P300 in healthy subjects. *Neuroscience Research*, *41*(1), 89–95. http://doi.org/10.1016/S0168-0102(01)00248-6.

Mullis, R. J., Holcomb, P. J., Diner, B. C., & Dykman, R. A. (1985). The effects of aging on the P3 component of the visual event-related potential. *Electroencephalography and Clinical Neurophysiology*, *62*(2), 141–9. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/2578944.

Nittono, H., Nageishi, Y., Nakajima, Y., & Ullsperger, P. (1999). Event-related potentialCorrelates of individual differences in working memory capacity. *Psychophysiology, 36*(6), 745-754.

Okada, Y. C., Kaufman, L., & Williamson, S. J. (1983). The hippocampal formation as a source of the slow endogenous potentials. *Electroencephalography and Clinical Neurophysiology*, *55*(4), 417–426. http://doi.org/10.1016/0013-4694(83)90130-X.

Olichney, J. M., & Hillert, D. G. (2004). Clinical applications of cognitive event-related potentials in Alzheimer's disease. *Physical Medicine and Rehabilitation Clinics of North America*, *15*(1), 205–33. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/15029906.

Osterhout, L., Allen, M. D., McLaughlin, J., & Inoue, K. (2002). Brain potentials elicited by prose-embedded linguistic anomalies. *Memory & Cognition*, *30*(8), 1304–12. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/12661861.

Papanicolaou, A. C., Loring, D. W., Raz, N., & Eisenberg, H. M. (1985). Relationship

Between Stimulus Intensity and the P300. *Psychophysiology*, *22*(3), 326–329. http://doi.org/10.1111/j.1469-8986.1985.tb01608.x.

Picton, T. W., & Hillyard, S. a. (1974). Human auditory evoked potentials. II - Effects of attention. *Electro Encephalography and Clinical Neuro Physiology*, *36*, 191–200.

Picton, T. W. (1992). The P300 wave of the human event-related potential. *Journal of clinical neurophysiology*, *9*(4), 456-479.

Polich, J. (1986b). Normal variation of P300 from auditory stimuli. *Electroencephalography and Clinical Neurophysiology*, *65*(3), 236–40. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/2420577.

Polich, J. (1990). P300, probability, and interstimulus interval. *Psychophysiology*, *27*(4), 396–403. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/2236442.

Polich, J. (2004). Neuropsychology of P3a and P3b: A theoretical overview. *Brainwaves and mind: Recent developments*, 15-29.

Polich, J. (2007). Updating P300: an integrative theory of P3a and P3b. *Clinical Neurophysiology : Official Journal of the International Federation of Clinical Neurophysiology*, *118*(10), 2128–48. http://doi.org/10.1016/j.clinph.2007.04.019.

Polich, J., & Bondurant, T. (1997). P300 sequence effects, probability, and interstimulus interval. *Physiology & Behavior*, *61*(6), 843–9. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/9177555.

Polich, J., & Comerchero, M. D. (2003). P3a from visual stimuli: typicality, task, and topography. *Brain Topography*, *15*(3), 141–52. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/12705810.

Ravden, D., &Polich, J. (1999). On P300 measurement stability: habituation, intra-trial block variation, and ultradian rhythms. *Biological psychology*, *51*(1), 59-76.

Resolução, H. De, Violinistas, M., Alexandre, R., Monteiro, M., Nascimento, F. M., Soares, C. D., … Ferreira, C. (2010). Temporal Resolution Abilities in Musicians and No Musicians Violinists. *Arquivos Internacionais de Otorrinolaringologia*, *14*(3), 302–308.

Ritter, W., Simson, R., Vaughan, H. G., & Macht, M. (1982). Manipulation of event-related potential manifestations of information processing stages. *Science (New York,N.Y.)*, *218*(4575), 909–11. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/7134983.

Rubel E. Ontogeny of structure and function in the vertebrate auditory system. In: Jackson M, editor. Handbook of Sensory Systems. New York: Springer verlag; 1978. pp. 135–237.

Squires, K., Wickens, C., Squires, N., Donchin, E. (1976) The effect of stimulus sequence on the waveform of the cortical event-related potential. *Science*.; 193:1142–1145.

Summerfield, C., Trittschuh, E. H., Monti, J. M., Mesulam, M. M., & Egner, T. (2008). Neural repetition suppression reflects fulfilled perceptual expectations. *Nature neuroscience*, *11*(9), 1004.

Sutton, S., Braren, M., Zubin, J., & John, E. R. (1965). Evoked-potential correlates of stimulus uncertainty. *Science (New York, N.Y.)*, *150*(3700), 1187–8. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/5852977.

Trainor, L. J., Desjardins, R. N., & Rockel, C. (1999). A Comparison of Contour and

Interval Processing in Musicians and Nonmusicians Using Event-Related Potentials. Australian Journal of Psychology, 51(3), 147-153.

Tremblay, K. L. (2007, May). Training-related changes in the brain: evidence from human auditory-evoked potentials. In *Seminars in Hearing* (Vol. 28, No. 02, pp. 120-132). Copyright© 2007 by Thieme Medical Publishers, Inc., 333 Seventh Avenue, New York, NY 10001, USA..

Uther, M., Kujala, A., Huotilainen, M., Shtyrov, Y., &Näätänen, R. (2006). Training in Morse code enhances involuntary attentional switching to acoustic frequency: Evidence from ERPs. *Brain research*, *1073*, 417-424.

Vesco, K. K., Bone, R. C., Ryan, J. C., & Polich, J. (1993). P300 in young and elderly subjects: auditory frequency and intensity effects. *Electroencephalography and Clinical Neurophysiology*, *88*(4), 302–8. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/7688285

Wayman, J. W., Frisina, R. D., Walton, J. P., Hantz, E. C., & Crummer, G. C. (1992). Effects of musical training and absolute pitch ability on event-related activity in response to sine tones. The Journal of the Acoustical Society of America, 91(6), 3527-3531.

Witelson, S. F., & Kigar, D. L. (1992). Sylvian fissure morphology and asymmetry in men and women: bilateral differences in relation to handedness in men. *Journal of Comparative Neurology*, *323*(3), 326-340.

Zhang, J., & Kourtzi, Z. (2010). Learning-dependent plasticity with and without training in the human brain. *Proceedings of the National Academy of Sciences*, *107*(30), 13503-13508.