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Exploring the nature of the P300 in normal hearing adults in response to filtered words

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ABSTRACT

The present study explored the nature of the auditory P300 in response to filtered words in ten normal hearing adults. P300 waveforms were elicited by a classic oddball paradigm, and recorded using a net of 128 electrodes (HydroCel Geodesic Sensor Net 128 1.0.). P300 waveforms from central, parietal, temporal right and temporal left regions were selected for data collection. P300 latencies and amplitudes for the largest deflection distinguishing responses to filtered from unfiltered words between 248 and 652 ms post stimuli were collected from each electrode in each region and these values were averaged obtain electrode group values. All filtered versions of the word successfully elicited P300 waveforms at all four recording locations in the form of large, vertex-positive deflections, which differed significantly ($p<0.05$) compared to the electrophysiological responses to the unfiltered stimulus. However, among the responses to the different filtered versions of the stimulus the overall tendency was that statistical differences could not be seen, neither in terms of amplitudes or latencies. The lack of substantial change in the P300 waveforms elicited by the different filtered versions of the stimulus word suggests the use of the P300 as a measure of filtered word performance is limited to the detection of a filtered version of a word and not the degree of filtering present in that word, at least within the filter range used in this study.

Key words

P300, LPFS test, CAPD, ERP, Filtered words, Language Impairment

Abbreviations

ACC: Acoustic Change Complex
[C]APD: (Central) Auditory Processing Disorder
EEG: Electroencephalogram
ERP's: Event Related Potentials
LI: Language Impairment
LPFS: Low Pass Filtered Speech

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INTRODUCTION

Low Pass Filtered Speech (LPFS) tests require the participant to repeat a series of words that have been low-pass filtered to sound as if the speaker is mumbling. These tests assess a person's ability to compensate for the loss of information caused by the filtering: an ability often referred to as auditory closure (Bellis, 2003).

There are several versions of the LPFS test (Farrer & Keith, 1981; O'Beirne, McGaffin & Rickard, 2012), each typically sharing three common features. First, the words used in these tests are monosyllabic with a consonant-nucleus-consonant structure. Second, each word is presented monaurally (Bellis, 2003; Farrer & Keith, 1981). Finally, the words are low-pass filtered at cut-off frequencies ranging from 500 to 1500 Hz with attenuation rates of 17 dB/octave or greater. This final feature of cut-off frequency has a particularly significant effect on LPFS test scores, with Farrer and Keith (1981) showing scores of approximately 90% for a LPFS test using a cut-off frequency of 1000 Hz, approximately 80% for a cut-off frequency of 750 Hz, and less than 60 % for a cut-off frequency of 500 Hz, in normal hearing children. In other words, harsher filtering leads to poorer subject performance.

Bocca, Calearo and Cassinari (1954) developed the first version of a LPFS test in the 1950s and found that patients with temporal lobe tumours performed poorly when asked to repeat filtered words presented to the ear contralateral to the tumour. Nowadays, LPFS tests are more commonly used in audiology as a part of the test battery for identifying patients with (Central) Auditory Processing Disorder ([C]APD) (Bellis, 2003; Chermak & Musiek, 1997). (C)APD has been described as a disorder making it difficult to hear in noisy environments and to understand degraded speech despite normal hearing thresholds (Jerger & Musiek, 2000). It "may be associated with difficulties in listening, speech understanding, language development and learning" (Jerger & Musiek, 2000, p. 468). A universally accepted definition of (C)APD and a gold standard for its diagnosis remain elusive, however, with numerous definitions and criteria currently in use in differing regions around the world (ASHA, 2005; BSA, 2011; Moore, 2006; NIDCD, 2001; Wilson & Arnott, 2013; Wilson, Heine & Harvey, 2004).

Despite being widely used in audiology as part of the assessment for (C)APD, LPFS tests have some clear limitations. Of primary concern is the confounding influence of non-auditory factors such as cognition, particular regarding memory, attention and language (AAA, 2010; Cacace & McFarland, 1998; Jerger et al, 2002; Jirsa & Clontz, 1990). These confounding influences are made worse by the high comorbidity of (C)APD with other conditions such as Language Impairment (Findlen & Roup, 2011; Sharma, Purdy & Kelly, 2009), and findings that persons with LI present with symptoms (Jerger & Musiek, 2000) and LPFS test scores similar to those observed in persons with (C)APD (Musiek & Chermak, 2007). This significantly affects the use of LPFS tests to differentially diagnose (C)APD from similar conditions such as LI.

In an attempt to counter some of the confounds facing LPFS, some researchers have turned to the Event Related Potentials (ERP's). ERP's are the changes in the brain's electrical potentials in response to a stimulus. These changes can be measured using surface electrodes placed on the scalp and differential averaging to extract the event related potentials from the overarching brain potentials unrelated to the stimulus event. ERP's normally occurs from 50 ms onwards after the stimulus onset, with earlier brain potentials thought to arise from sensory rather than perceptual or cognitive processes (Jeste & Nelson, 2009). Martin, Tremblay and Korczak (2008) raised the point that;

> "Speech-evoked auditory event-related potentials (ERPs) provide insight into the neural mechanisms underlying speech processing. For this reason, ERPs are of great value to hearing scientists and audiologists. […]Speech-evoked ERPs provide a means of tapping an individual's speech processing capacity, who, because of auditory, linguistic, and/or cognitive reasons cannot be reliably assessed using standard behavioral measures. Second, ERPs may reflect neural processing of speech at different stages within the auditory system, making it possible to differentiate whether perceptual confusions result from the inability to detect or discriminate physical properties of the acoustic signal." p. 285.

This is supported by several authors acknowledging the potential for ERPs to be used to diagnose (C)APD (e.g. AAA, 2010; Dawes & Bishop, 2009; Jerger et al, 2002; Jerger & Musiek, 2000; Liasis et al, 2003).

Of the many available ERPs, the auditory P300 has proven to be widely used in the assessment of auditory processing in humans. It consists of two main components known as the P3a and the P3b (Duncan et al, 2009), although the current study will mainly focus on the P3b. Many authors describe the P3b as a vertex positive peak in the brain's electric activity occurring approximately 300 milliseconds after stimulus onset that is best recorded from centroparietal regions of the scalp with stimuli presented under an oddball paradigm. Within the classic oddball paradigm, two stimuli are presented in series with one being the "standard" (or "frequent") stimulus as it is presented 80% of the time, and the other being the "oddball" (or "deviant" or "target") stimulus as it is randomly presented 20% of the time. In the active condition, the participant is asked to indicate (by pressing a button, raising his or her finger, or counting) each time he or she hears the oddball stimulus (Duncan et al, 2009; Martin et al, 2008; Polich, 2007). The P3b is affected by various factors including the degree of difficulty of the task with more difficult tasks (e.g, more subtle differences between frequent and oddball stimuli) typically resulting in P300b waves that are longer in latency and smaller in amplitude (Kok, 2001; Martin et al, 2008; Porbadgnik et al, 2010).

P300 is widely believed to reflect processes of attention, memory and decision making (e.g. Butcher, 1992; Jeste & Nelson, 2009; McPherson, 1996). Polich (2007) presents one of the main theories in line with such beliefs, the content-update theory. According to this theory, if the current stimulus is identical to the one represented in the participants working memory, then the earlier, sensory potentials (N100, P200, N200) will stay unchanged and the P300 will not be elicited. However, if there is a sensorial detectable difference between the current stimulus and the ones represented in the participants working memory, and the participant directs his or her attention to this (in other words, if the participant has a task associated with the stimuli being different), then the brain allocates neural activity to process the new stimulus, which in turn is measured as the P300 (Polich, 2007). Consistent with this reasoning, it is believed the longer latencies and smaller amplitudes observed in P300 waveforms associated with more difficult tasks is due to "less effective attentional resource allocation or slowing of the information processing speed" (Katayama & Polich, 1996, p. 33). However, it should be emphasized that it is yet not entirely clear what exact underlying auditory processes cause the P300 to be elicited (Berman et al, 2006; Martin et al, 2008; Polich, 2007). Despite the lack of complete comprehension of the neural origins of the P300, previous studies suggest that the P300 has potential to separate individuals with (C)APD from those with other conditions (Jirsa & Clontz, 1990; Krishnamurti, 2001). Moreover, since language elements appear to have a greater effect on AEPs occurring after the P300, such as the N400 (Duncan et al, 2009), an auditory evoked P300 in response to a filtered word might provide a better measure of the listener's auditory rather than language processing abilities. Even though P3a in its lack of dependence of directed attention may seem to be an attractive measure, this study will use the P3b since the P3a is only present in 10-15 % of young adults (Polich, 1988).

While many types of stimuli have been used to elicit P300 waveforms, the majority have been short in duration. The use of longer duration stimuli, such as monosyllabic CVC words, could give rise to a complex waveform consisting of several overlapping responses to the different parts of the word stimulus. Martin and Boothroyd (1999) named such a complex the Acoustic Change Complex (ACC), appearing as a protracted version of the P300 elicited by short-duration stimuli. Whether the waveforms elicited in the present study are truly P300 waveforms or ACCs will not be investigated with all vertex positive peaks in brain electric activity occurring approximately 300 milliseconds after stimulus onset being referred to as P300 waveforms.

To the author's knowledge, there have been no studies published on the use of low-pass filtered word stimuli to elicit the P300. This is despite the P300 having been elicited by a wide range of auditory stimuli (e.g. Collard, Corley, MacGregor & Donaldson, 2008; Massa, Rabelo, Matas, Schochat & Samelli, 2011; Uemura & Hoshiyama, 2010) such that there appears to be no auditory stimulus unable to induce P300 (when using the classic odd-ball paradigm).

The purpose of this study is to explore the nature of any auditory P300 waveform activity in response to filtered words, as an initial step towards determining whether the P300 could provide a better measure of the listener's auditory rather than language processing abilities. In particular, the study will determine:

1. Can a P300 be recorded using filtered word stimuli?
2. If so, from which electrode positions can the largest P300 amplitudes be recorded?
3. If so, does amount of word filtering affect the P300 waveform?

Based on previous reports of the P300, we hypothesize that a P300 will be recorded using filtered word stimuli, that it will be largest over the centro-parietal region of the scalp, and it will be smaller and later as the amount of filtering is reduced.

METHODS

Research Design

A single group repeated measures design was used in this study.

Participants & Ethics

Ten volunteers, (7 females, 3 males) between the ages of 18-38 years old, with hearing thresholds of 15 dB HL or weaker at octave intervals 250-8000 Hz (air conduction), participated in this study. The modified Houghson-Westlake technique (Carhart & Jerger, 1959) was used for all audiometric assessments. Two of the participants were left-handed, while the remaining 8 participants were right-handed. The participants were all students from major Universities in Brisbane, Australia. Participants were recruited through personal contacts and through advertising on notice boards on the St Lucia campus, University of Queensland. Prior to conducting the study, ethical clearance was obtained from the University of Queensland Behavioural and Social Sciences Ethical Review Committee (BSSERC, Approval No. 2011000065) in accordance with the National Health and Medical Research Council guidelines. All participants agreed in writing to the conditions of the study. Initially 11 participants were recruited for this study, but after data collection one participant was excluded due to severe eye blinking at each stimuli presentation, resulting in indecipherable electrophysiological recordings. After this exclusion, the 10 participants described above remained.

Procedure

Preparation

The participants were fitted with appropriately sized net of 128 electrodes (HydroCel Geodesic Sensor Net 128 1.0.) that had been soaked in a potassium chloride solution to optimize electrode contact impedance to the scalp. The electrode net was placed on the participants' head so that the Cz-electrode was placed on the participant's true vertex (measured as the point halfway between the nasion and inion, and half way between the preauricular points). Electrode impedances were kept below 30 kΩ where possible, although some electrode impedances were noted to occur between 30-50 kΩ.

P300 Recording

When the impedance requirements were met the participant was seated upright in a comfortable chair at approximately 0.5-1 meter distance in front of the speakers (Altec Lansing Model 220) in a sound treated and electrically shielded room. The participant then, in a single test session, listened to auditory stimuli presented in 4 blocks, each created with E-Studio Professional version 2.0.8.74 running E-Prime 2.0. Each block consisted of 80 presentations of the unfiltered recording of the word 'bed' (standard stimuli) and 20 presentations (at random) of a filtered recording of the word 'bed' (target stimulus), at a stimulus rate of one per 1500 ms.

The stimulus 'bed' was copied as a wave file from the ninth word in List 14 of the National Acoustics Laboaratories Arthur Boothroyd (NAL AB) wordlists and had been spoken by a male speaker of Australian English. This wave file was then imported in Audacity 2.0.2. for Windows (Released under GLP v.2) and five versions of the word were created: one unfiltered (standard) and four filtered (targets). Each filtered version was created by passing the unfiltered version through the low-pass filter function of Audacity 2.0.2. (by Dominic Mazzoni and modified by David R. Sky) using a 48 dB/ octave roll-off rate and cut-off frequencies of 1000 Hz, 2000 Hz, 3000 Hz or 4000 Hz. All five versions of the word 'bed' were then normalized through the normalization function of Audacity 2.0.2. (written by Dominic Mazzoni) to a maximum output level of –1.0 dB. Each stimuli had a duration of 688 ms.

All stimuli were presented to the participants via the speakers at a peak output level of 75 dBA (measured with a Bruel and Kjaer 2235 SLM with a ½ inch free field at 1 m from the speakers at the approximate height of a subject's head). Each participant was instructed to minimize his or her body movements and to stay relaxed with eyes closed throughout all test blocks, and to respond to the rare stimuli by pressing a button on a response pad each time they heard a presentation of a filtered word. Blocks 1 to 4 were presented so that the order of low-pass filtering of the oddball stimulus was 1000 Hz, 2000 Hz, 3000 Hz and 4000 Hz respectively. Each participant was given as short rest break between blocks with the total time being 8-10 minutes. With preparations as described above and subsequent undertakings such as cleansing of electrodes included, the time spent on testing each participant equaled approximately 60-90 minutes. Furthermore, the analysis and interpretations of the obtained recordings turned out to be immensely time-consuming.

The P300 waveforms were recorded via Net Station Dense Array EEG Workstation Software version 4.5.1. coupled to a Net Amps 300 amplifier (dynamic range: ±200 mV). The ongoing EEG activity recording during each block was processed as follows:

1) A 0.1 Hz high-pass, first order filter was used to remove any direct current shift in the EEG activity.
2) A 30 Hz low-pass, finite impulse response-filter with a pass band gain of 99.0%, a stop band gain of 1.0%, and a roll off rate of 2.00 Hz, was used to identify neural activity of cortical origin.
3) The ongoing EEG activity was segmented into 1500 ms blocks, each starting 100 ms before stimuli onset and finishing 1400 after stimuli onset.
4) An artefact detection function was used to remove artifacts in the recording. Channels were marked as bad for the entire recording if they were bad for more than 20% of the segments. Segments were marked as bad if they contained more than 10 bad channels, a eye blink or eye movement. The bad channel threshold was set at a maximum amplitude minus minimum amplitude >200.00 µV calculated for an entire segment using an 80 ms moving average. The eye-blink threshold was set at a maximum amplitude minus minimum amplitude >140.00 µV within 640 ms of stimulus onset performed within moving average of 80 ms. The eye movement threshold was set at a maximum amplitude minus minimum amplitude of >55.00 µV within 640 ms post stimuli onset performed within moving average of 80 ms.
5) All bad channels were replaced using Geodesic default algorithm for bad channel replacement.

6) The segments for the unfiltered and each filtered version of the stimulus word "bed" were linearly averaged separately. This resulted in averaged waveforms to each of these stimuli.
7) A montague operation was conducted using the HydroCel Geodesic Sensor Net 128 1.0. average reference (average across all electrodes) with bad channels excluded from this reference.
8) A baseline correction was applied relative to a segment of each recording from 100 ms before stimuli onset until onset.

Response accuracy and timing

Each participant's response accuracy (correct or incorrect response to the oddball stimuli) and timing (the time taken to press the response button after the onset of each oddball stimulus presentation) were recorded with E-Studio Professional version 2.0.8.74 running E-Prime 2.0.

Data collection

P300 waveforms from central, parietal, temporal right and temporal left electrode groups (see *figure 1*) were selected for data collection. The reason why the number of investigated electrodes was limited to the ones within these four groups was that visual inspection of the entire electrode formation indicated that responses of P300 character did not appear at frontal or occipital sites. P300 latencies and amplitudes for the largest deflection distinguishing responses to filtered from unfiltered words between 248 and 652 ms post stimuli were collected from each electrode in each group and these values were averaged obtain electrode group values. All P300 latencies were calculated as the time in ms from stimulus onset to the point of maximum deflection. The P300 amplitudes were measured in three different ways as per Hui Hui (2012). The maximum amplitude was defined as the largest amplitude on the P300 waveform relative to prestimulus baseline. The mean amplitude was defined as the average amplitude of all points in the 248 ms to 652 ms window. The adaptive mean amplitude was defined as the mean amplitude of all points representing 25% of the maximum amplitude in either direction from the point of maximum amplitude (i.e. before and after the latency of the point of maximum amplitude) not extending beyond the 248 ms to 652 ms window. As mean amplitude did not add anything to the study's final results, only maximum amplitude and adaptive mean amplitude will be presented under the results section.

The dependent variables were defined as the P300 latency, maximum amplitude, mean amplitude and adaptive mean amplitude, and the correct response rate and response time. The independent variables were defined as the filter levels of the target stimuli (unfiltered vs. 1000 Hz vs. 2000 Hz vs. 3000 Hz vs. 4000 Hz) and region of the recording electrode group (central vs. parietal vs. temporal right vs. temporal left).

Data Analysis

Non-parametric statistics were used for all data analysis as visual inspection of the histograms, Q-Q plots, detrended Q-Q plots and Box & Whisker plots of all collected data revealed several breaches of normality that could not easily be fixed by excluding outliers or transforming the data. Friedman ANOVA analyses were used to determine whether P300 latencies, maximum amplitudes, mean amplitudes or adaptive mean amplitudes differed within each filter level and/or recording electrode region. In the cases where differences were detected, Wilcoxon signed rank analyses were used to identify the exact nature of these differences. All statistical analyses were performed at the 5% level using IBM SPSS Statistics Version 21.0.0.0 32 bit edition for Windows (IBM SPSS, 2012).

RESULTS

Figure 2-5, shows the grand average waveforms from all participants to the unfiltered and filtered word stimuli. *Table 1* shows medians and minimum to maximum ranges of P300 adapted amplitudes, P300 maximum amplitudes and P300 latencies for each region and filter level, as well as behavioural response time and percentage of correct responses for each filter level. *Table 1* also shows statistical comparisons of P300 adapted amplitudes, P300 maximum amplitudes and P300 latencies between each region for each filter level, and between each filter level for each region.

All four filtered word stimuli successfully elicited P300 waveforms at all four recording locations in the form of large, vertex-positive deflections in the 248 and 652 ms time window post-stimulus compared to the absence of such deflections in response to the unfiltered stimulus.

Within each recording location, the amplitude of these P300 waveforms to each filtered word stimulus differed significantly ($p<0.05$) from the amplitude of the waveform to the unfiltered stimulus in the same latency range. However, the amplitudes of these P300 waveforms did not differ significantly ($p<0.05$) amongst the filtered stimuli (with the exception of the amplitudes of the P300 waveforms to the word played through filters with cut-off frequencies of 4 kHz and 1 kHz at the central region, where the word played through low-pass filter with a cut-off frequency of 4 kHz elicited greater P300 Maximum Amplitudes and greater P300 Adapted Amplitudes compared to what was elicited by the word played through low-pass filter with a cut-off frequency of 1 kHz). No such differences were observed in the P300 latencies.

Within each filter level, the amplitude of these P300 waveforms only differed significantly ($p<0.05$) amongst recording locations for of the amplitudes of the P300 waveforms to the word played through filters with cut-off frequencies of 2 kHz and 1 kHz. The P300 Adapted Amplitudes differed for responses to the word played through filters with cut-off frequencies of 2 kHz (larger amplitudes recorded at the parietal region, compared to temporal right and temporal left regions) and P300 Maximum Amplitudes differed for responses to the word played through filters with cut-off frequencies of both 2 kHz and 1 kHz (larger amplitudes recorded at the parietal region, compared all other investigated regions for both cut-off frequencies). No such differences were observed for the P300 latencies.

No significant ($p<0.05$) differences were observed in the behavioural measures (percentage correct responses and response times) amongst the different filter levels.

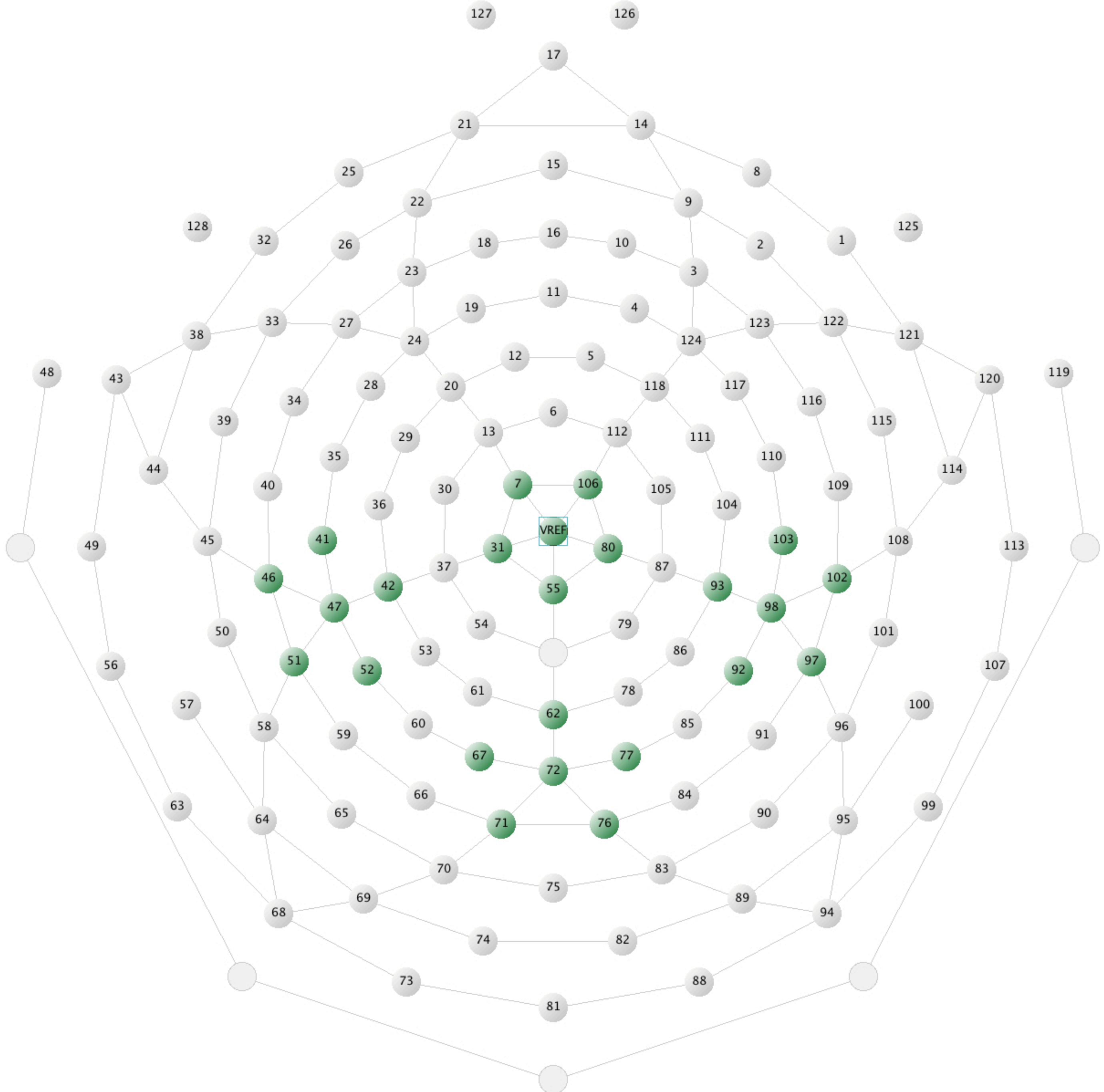

Figure 1. Formation of electrodes as seen from above. Participants nose at the top of the picture between electrode 127 and 126, ears between electrode 48, 43 and 49 respectively electrode 119, 120 and 113. Investigated groups marked as green.

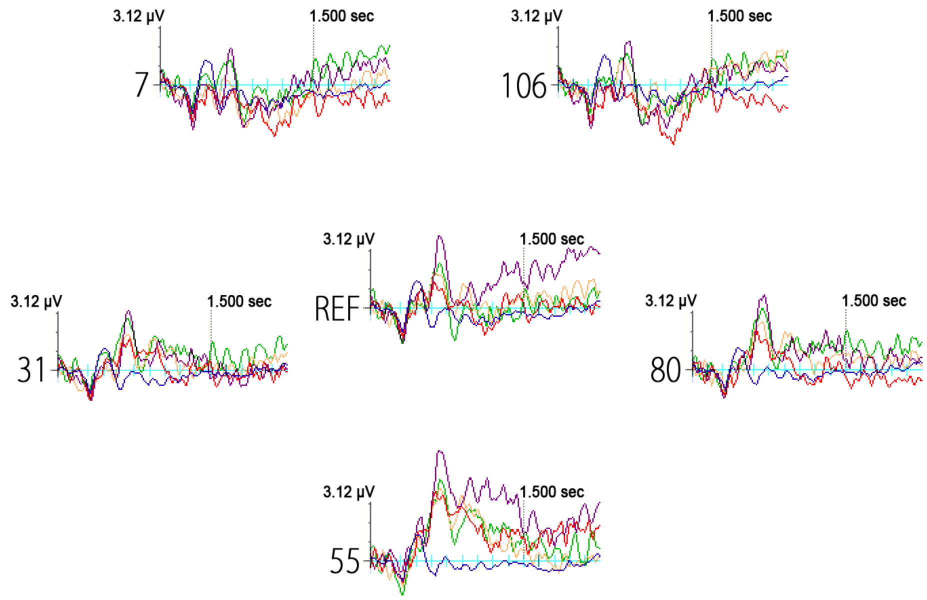

Figure 2. Average recorded activity from all participants' central regions. Responses to the unfiltered version of the stimuli marked as dark blue, responses to filtered versions of the stimuli marked as red (1 kHz), orange (2 kHz) green (3 kHz) and purple (4 kHz).

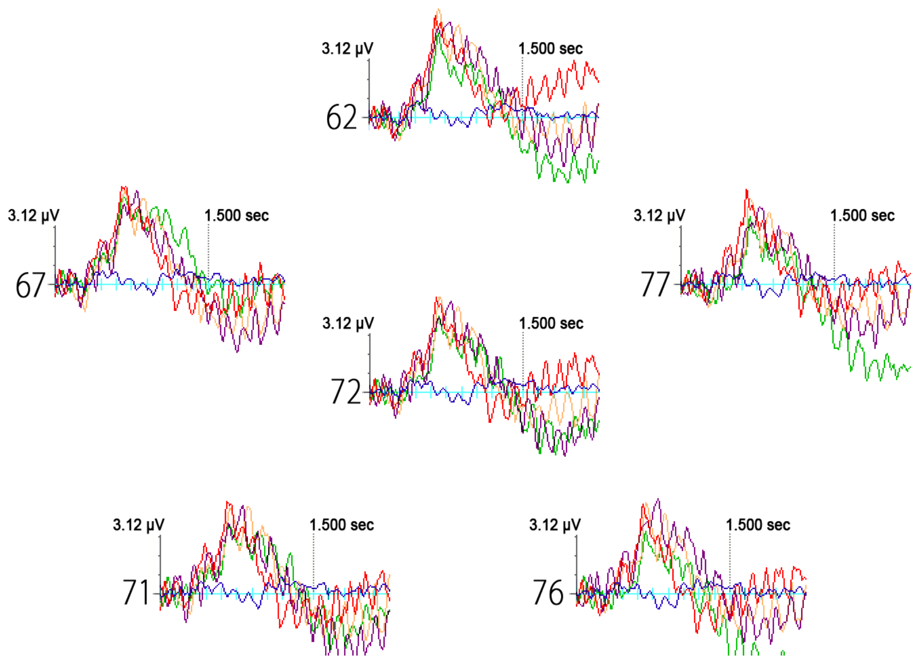

Figure 3. Average recorded activity from all participants' parietal regions. Responses to the unfiltered version of the stimuli marked as dark blue, responses to filtered versions of the stimuli marked as red (1 kHz), orange (2 kHz) green (3 kHz) and purple (4 kHz).

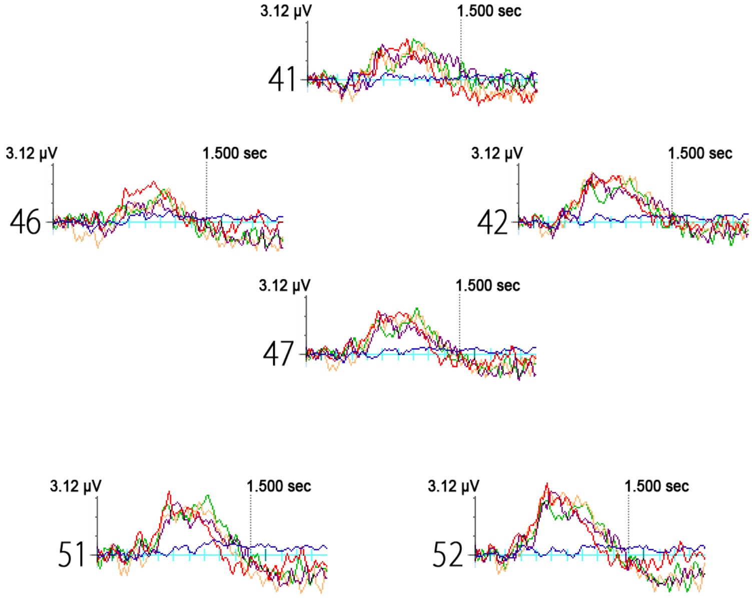

Figure 4. Average recorded activity from all participants' temporal left regions. Responses to the unfiltered version of the stimuli marked as dark blue, responses to filtered versions of the stimuli marked as red (1 kHz), orange (2 kHz) green (3 kHz) and purple (4 kHz).

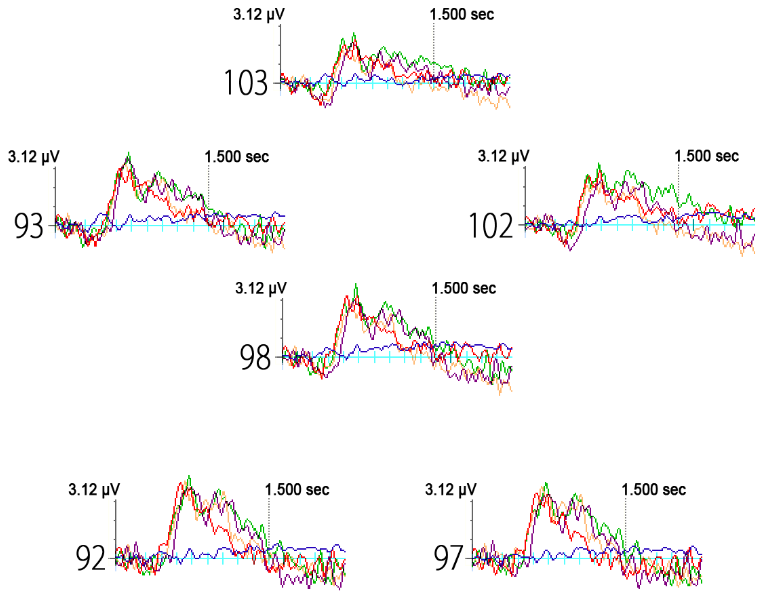

Figure 5. Average recorded activity from all participants' temporal right regions. Responses to the unfiltered version of the stimuli marked as dark blue, responses to filtered versions of the stimuli marked as red (1 kHz), orange (2 kHz) green (3 kHz) and purple (4 kHz).

Table 1. P300 amplitudes and latencies, and response times and percentage correct responses for all 10 subjects, minimum to maximum ranges presented in regular typography and medians presented in italic. Comparisons of activity by region for each filter level are presented horizontally, and comparisons of activity by filter level for each region are presented vertically. p stands for p-value (Friedman) and W stands for Wilcoxon. Abbreviations used under Wilcoxon: Unfiltered (U), 1 kHz (1), 2 kHz (2), 3 kHz (3), 4 kHz (4), Central (C), Parietal (P), Temporal left (T_L), Temporal right (T_R). * - the amplitudes reported for the unfiltered word condition represent the amplitude of the background noise present in the region where the P300 waveform had been observed in the filtered word conditions.

	Filter level					**Statistical comparison**		
Region	**Unfiltered ***	**1 kHz**	**2 kHz**	**3 kHz**	**4 kHz**	**p**	**W**	
			P300 Adapted Amplitude (μV)					
Central	0.62-3.46 *1.61*	0.73-5.46 *2.38*	1.30-6.30 *3.45*	1.77-4.98 *3.50*	1.58-7.50 *3.83*	.000	(1,2,3,4)> U; 4>1	
Parietal	-0.69-3.56 *1.34*	0.72-10.31 *6.35*	2.51-11.14 *5.33*	0.08-8.68 *5.18*	-0.73-13.13 *5.87*	.025	(1,2,3,4)> U	
Temporal left	-0.48-1.77 *1.15*	0.59-7.06 *3.23*	-0.01-7.94 *2.82*	-1.55-6.06 *3.31*	-0.44-8.44 *2.27*	.020	(1,2,3,4)> U	
Temporal right	0.42-3.13 *0.93*	0.96-8.13 *3.09*	1.74-8.05 *3.00*	0.64-7.92 *3.75*	0.14-7.47 *4.25*	.001	(1,2,3,4)> U	
	.062	.086	.033	.187	.118			**p**
			P>(T_L, T_R)					**W**
			P300 Maximum Amplitude (μV)					
Central	0.78-3.90 *1.85*	1.20-6.14 *2.99*	1.67-6.78 *4.20*	2.44-6.56 *4.03*	2.54-8.24 *4.66*	.000	(1,2,3,4)> U; 4>1	
Parietal	-0.34-3.92 *1.57*	1.71-12.50 *6.83*	3.38-12.58 *5.98*	0.56-9.26 *6.43*	0.32-13.97 *6.89*	.020	(1,2,3,4)> U	
Temporal left	0.12-2.05 *1.30*	1.38-7.90 *4.00*	0.57-8.75 *3.77*	-0.59-6.57 *3.93*	-0.02-8.95 *2.75*	.004	(1,2,3,4)> U	
Temporal right	0.60-3.47 *1.20*	1.70-9.51 *3.48*	2.05-9.47 *3.82*	1.10-10.10 *4.23*	0.61-8.66 *4.92*	.000	(1,2,3,4)> U	
	.106	.041	.018	.145	.145			**p**
		P>(C, T_L, T_R)	P>(C, T_L, T_R)					**W**
			P300 Latency (ms)					
Central		225-666 *402*	293-692 *547*	249-693 *393*	315-667 *405*	.948		
Parietal		307-785 *388*	287-775 *465*	293-731 *431*	274-728 *403*	.948		
Temporal left		383-787 *481*	301-713 *435*	250-707 *511*	237-729 *496*	.516		
Temporal right		257-643 *415*	288-655 *449*	311-620 *431*	171-592 *412*	.840		
		.131	.948	.339	.392			**p**
			Behavioural Response Time (ms)					
		358-716 *438*	389-732 *519*	352-684 *576*	339-667 *543*	.151		
			Behavioural Correct Responses (%)					
		95-100 *100*	95-100 *100*	95-100 *100*	95-100 *100*	.261		

DISCUSSION

The purpose of this study is to explore the nature of the auditory P300 in response to filtered words, as an initial step towards determining whether the P300 could provide a better measure of the listener's auditory rather than language processing abilities. In particular, the study will determine:

1. Can a P300 be recorded using filtered word stimuli?
2. If so, from which electrode positions can the largest P300 amplitudes be recorded?
3. If so, does amount of word filtering affect the P300 waveform?

P300 waveforms were able to be recorded using filtered word stimuli with all four of this study's filtered word stimuli eliciting a P300 waveform compared to the response to the unfiltered stimulus. Taking the content-update theory (Polich, 2007) in consideration, this finding indicates that the method used in this study serves well to obtain an electrophysiological measure of a listeners detection of a difference between a filtered word compared to an unfiltered one.

Electrode location had little effect on the P300 waveforms recorded in this study, with the parietal location provided larger amplitudes to the 1000 Hz and 2000 Hz filter levels only. When an amplitude difference between regions was detected, it was consistent with previous literatures portrayal of the P300 as a potential appearing the clearest at the centro parietal sites of the scalp (Duncan et al, 2009; Martin et al, 2008; Polich, 2007). However, the P300 waveforms in the present study were measurable at all of the four investigated regions. This implies that electrode location (within the locations tested) may not be critical when recording P300 waveforms in response to filtered words, but if activity should be recorded from one location only, then the parietal region is preferable.

Amount of filtering also had little effect on the P300, with all filter levels eliciting similar P300 waveforms. This was consistent with the absence of an effect of filtering on the behavioural measures. A possible explanation for this could be that none of the cut-off frequencies provided a sufficiently difficult task to provoke a failure to identify a deviant stimulus. Such a ceiling effect is consistent with the worst percentage of behavioural correct responses for any participant at any filter level being 95%. In two cases, however, the amount of filtering did affect the P300 amplitudes. In the central group of electrodes, the word played through low-pass filter with a cut-off frequency of 4 kHz elicited greater P300 maximum amplitudes and greater P300 adapted amplitudes compared to what was elicited by the word played through low-pass filter with a cut-off frequency of 1 kHz. This result is difficult to explain as more difficult tasks have previously resulted in decreased P300 amplitudes (Kok, 2001; Martin et al, 2008; Porbadgnik et al, 2010). For instance, Parasuraman's (1980) data indicated that when listeners were having trouble identifying which tone they'd heard they elicited P300's with decreased amplitudes as a response to that tone, compared their P300 responses to tones they had less trouble identifying. Assuming this also applies for P300's elicited by filtered words, our results seem to be indicating that it was more difficult for the participants to separate the stimuli played through a filter with a cut-off frequency of 1 kHz than the stimuli played through a filter with a cut-off frequency of 4 kHz, compared to the unfiltered stimuli. While this could be a finding unique to this study, another possible explanation could lie in the order of filtering used in the study. As the cut-off frequency of the filter in the present study was gradually increased throughout the test session, this was expected to result in sequentially less information being subtracted from the deviant stimuli, making it more similar to, and in theory harder to separate from, the standard stimuli. This increasing level of difficulty may have been offset, however, by the participants' improving their ability to complete the oddball task, and therefore requiring fewer cognitive resources to complete the tasks, as the testing progressed.

The lack of substantial change in the P300 waveforms elicited by the different filtered versions of the stimulus word suggests the use of the P300 as a measure of filtered word performance is limited to the detection of a filtered version of a word and not the degree of filtering present in that word in normal adults. This could prove to be useful in the clinical setting if it can be shown that subjects with APD do not show the same equal detection abilities across the filter range used in the present study. However, robust age normative data, as well as shorter test duration in order to ease testing of the P300 in children, is required prior to clinical implementation.

To further investigate which parameters may change due to difficulties to, or inability of, detection of filtered words, future research could first develop a psychometric curve of normal hearing adult listeners' behavioural responses to odd-ball tasks such as those given in this study. Thereafter it would be possible to compare the P300's elicited by a word at a filter level that barely affects behavioural performances, a filter level that slightly degrades behavioural performances and a filter that clearly degrades behavioural performances. Future research should also alter the task order for every participant to exclude all kind of uncertainty regarding habituation. A possible way to obtain the psychometric curve is to perform an adaptive behavioural test using the word "beg" as stimulus. When conducting a study of that type, one might also consider using a higher number of observations, as compared to this study, enabling investigation of possible correlations between P300 latencies and behavioural response time.

Several limitations must be noted in the present study. The findings cannot be generalized to children (a population more likely to undergo a (C)APD assessment) as the auditory P300 continues to develop throughout childhood (Duncan et al, 2009). The present study also failed to determine participant mental health with previous studies suggesting that some mental conditions such as schizophrenia can influence P300 (Picton, 1992).

While this study is part of a larger study on how to separate auditory processing deficits from language impairments it should be mentioned that even if P300 eventually proves to be able to separate auditory processing from language processing, the usage of the P3b itself has its limitations. One of the limitations is the fact that P3b needs directed attention to the task to be elicited (Duncan et al, 2009). This implies that a method involving recording P300 will, even though it is electrophysiological, not be truly objective. If a patient has normal P300 it indicates that the CANS functions well, but in case of abnormal P300 there will still be an uncertainty whether it is due to a deficit in the CANS or if it could be as a result of the participants lack of ability to direct attention.

CONCLUSION

This study has revealed that low-pass filtered words could be used to elicit P300 in normal hearing adults when recorded from central, parietal, temporal scalp regions. The lack of substantial change in the P300 waveforms elicited by the different filtered versions of the stimulus word suggests the use of the P300 as a measure of filtered word performance is limited to the detection of a filtered version of a word and not the degree of filtering present in that word, at least within the filter range used in this study.

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