Investigation of CAEP components in different human ethnic groups based on their native languages

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Abstract

Objective: Understanding and discovering neural mapping in brains that are interpreting human languages is a very difficult and complex process. However, this paper explored the cortical auditory evoked potentials (CAEP) in different human ethnic groups to give us the ability to estimate and discover the hearing process in the human brain more efficiently. We investigated and compared the patterns of neural activity of the CAEP for normal hearing ethnic groups among Malay and Chinese groups.

Methods: The recorded CAEP signals that were evoked by simple pure tones and complex sounds naturally produced by Malay (consonant-vowels) were averaged and listed. A t-test and a two-way ANOVA were used to determine the significant differences in the average CAEP amplitude and latency for the responses elicited by different stimuli. Finally, classification algorithms were used to discover the human brain's abilities in distinguishing between stimulus contrasts.

Results: The mean amplitude of the auditory N1 and P1 were weakened in the Chinese group compared with Malay group. In the Chinese group, the P3 component had large values for latencies and most of the amplitudes compared with the Malay group. The classification performances for the Chinese group was excellent and reached a high score for all classifier algorithms used.

Conclusion: The Chinese group had a slightly higher probability of hearing loss than the Malay group. Furthermore, the Chinese group showed a very good distinguishing ability in recognizing auditory stimuli, and they had a higher classification accuracy compared with the Malay group.

Keywords: Classification, consonant-vowel, cortical auditory evoked potential, ethnic groups, feature extraction

INTRODUCTION

Human social interaction requires hearing ability to communicate through language, speech, and acoustic patterns that vary in both frequency and intensity (1). Hearing enables us to socialize, work, interact, and even relax. It also helps in keeping us safe by warning us of potential dangers. Moreover, hearing provides us enormous sources of information. The hearing process in the brain has slight differences according to humans' different languages, environments, and cultures. Human languages play a vital and important role in building and changing the hearing map in the human brain. Thus, it is expected that the hearing process in human ethnic groups will have differences in interpreting sounds. Therefore, the brain's cortical signals must have some changes.

In previous studies, Osterhout et al. reported a review on event-related potentials (ERPs) in the brain related to human language. They reviewed studies on changing the cortical auditory evoked potentials (CAEP) components (N400, P300 and P600) for native (English) and non-native language speakers. The CAEP components (N400, P300 and P600) exhibited large activities. Finally, they concluded that we knew little about the cognitive and neural processes made manifest by these language-sensitive CAEP effects (2).
Näätänen & Tiitinen in 2014, reported that the CAEP responses were proved to be closely related to each other by presenting vowel sounds of closely related language groups (Estonian and Finnish) to speakers of these languages. The results showed that the Estonian subjects had a large mismatch negative (MMN) to a vowel sound of their own language (/õ/) when it was presented as a deviant stimulus. In contrast, the same deviant stimulus elicited a much smaller MMN response in Finnish subjects (3).

Evidence for the impact of speech characteristics on ERPs were discussed and the effects of stimulus frequency and complexity on the components of ERPs during passive listening experiments were detailed (4). The study used tone bursts in the speech frequency range (400/440, 1500/1650, and 3000/3300 Hz), words (/bad/ vs /dad/), and consonant-vowels (CVs) (/ba/ vs /da/). The authors concluded that the magnitude of N1 and MMN for tones were closely intertwined, with both reflecting the tonotopy of the auditory cortex. In a different study, Pratt et al. tested the potential components that were evoked by the response to a 10% or 50% frequency increase from 250 or 4000 Hz tones, presented at 500-ms intervals. The results showed that the P50, N100, and P200, and N100, and P200 components exhibited double peaks at bilateral and right temporal sites, and the authors concluded that brain activity changed with respect to frequency changes in direction, base frequency, and magnitude (5). A researcher used English consonant vowels on 10 native English speakers to determine the MMN responses to a variety of speech stimuli in a multiple deviant paradigm. The results showed that MMN responses to a good acoustic speech contrast did not reach significant effects. However, the study results showed that the MMN could be evoked by speech stimuli with large, single acoustic deviances, within a multiple deviant paradigm protocol (6).

Ethnic groups have differences in brain responses due to the auditory stimulus, with regard to their culture, religion, habits or ethnicity. Also, ethnic groups show differences in terms of hearing and hearing loss (7). Ethnic groups also differ genetically, so some diseases are more related to certain ethnic groups (8). Hearing loss might be related to that reason. Therefore, more studies are required to understand these differences in brain responses due to the auditory stimulus, especially studies related to the CAEP responses. These studies could help in oral rehabilitation and in developing the new generation of efficient hearing aids.

The aims of this study were to (1) determine the effects of pure tones and naturally-produced Malay CVs on the latency and amplitude of ERP components on both Malay native subjects as well as with Chinese subjects and compare the effects of their ERP components with each other to detect if there was an indication of hearing loss; (2) determine which CAEP component among P1, N1, P2, N2, and P3 was dominant in both the stimuli contrasts and for both tested subject ethnic groups; and (3) classify the brain responses to auditory stimuli by using five classifying algorithms on both subject ethnic groups, and classify the CAEP responses into ethnic groups.

METHODS

The proposed methodology is shown in Figure 1 and is elaborated further in the following sections.

Participants / Subjects

The study was conducted on two groups of participants. All participants involved in this study were tested by the Otorhinolaryngology, Ear, Nose, and Throat (ENT) department at Medical Centre using routine pure tone audiometry measurements (Association, 2005):

Fifteen right-handed adult Malay males (mean age = 23.5±3.2 years).

Fifteen right-handed adult Chinese males (mean age = 22.5±1.55 years).

The ENT department at the Medical Centre of the University Hospital confirmed that all subjects possessed a normal range of pure tone audiometry responses. All subjects showed normal audiologic presentation in both ears (air conduction thresholds 20 dB hearing level (HL) from 125-4000 Hz bilaterally, 40 dB HL at 6000 and 8000 Hz, and pure-tone average (PTA; average from 500-4000 Hz) 15 dB HL (9).

Each participant was asked to read, understand, and sign a consent form prior to commencing with the experiment. A simple Mini- Mental State Examination test was also conducted prior to the experiment to diagnose the subject’s mental abilities, memory capabilities, and attention and language deficiencies (10). Otoscopy was performed on both ears to exclude the presence of excessive cerumen and ensure that there were no obstacles towards preventing normal hearing. The experimental protocols were approved by the Human Ethics Committee. The study was conducted under the Eth-...
ics (Medical Ethics Committee, Medical Center. Ethics Committee/IRB Reference Number: 1045.22). Written information consent forms were given and explained, which were signed by the participants. All participants showed 100% of awareness with healthy normal abilities and responses. However, the test was carried out for more than the required number of subjects. Some subjects’ recordings had artifacts, noises, recording calibration, and device setting problems. The study selected the most successful recording signal, in which it was free of artifacts and it was a noiseless signal. The successful recording signals were from 15 subjects for the Malay group (MG) and 15 subjects for the Chinese group (CG) only.

Stimulus
The study was done in a passive listening condition and consisted of two disparate types of auditory stimuli; pure tone frequency burst (1000 Hz versus 4000 Hz) and speech articulation features that differed by one phoneme – voice/voiceless discrimination ba versus da (/ba-da/) characterized by CV. All stimuli were presented at approximately 85 dB SPL. However, the 1000 Hz/da stimulus was always considered the standard stimulus and the 4000 Hz/ba stimulus was always considered as the deviant stimulus (11).

The tone stimulus was 200 ms in the duration generated by the Matlab software program (mathwork.com), with (fall time = 10 ms, plateau time = 190 ms), represented at two different frequencies, 1000 Hz and 4000 Hz tone stimulus (12). The natural digitized CV speech tokens were produced by a female Malaysian Malay native speaker and recorded at 44,100 Hz sampling frequency. The tokens were edited into 200 msec in duration by removing the vibration of the vocal cord portion, the end part of the steady state vowel, and windowing the offset.

The stimuli were presented with a pseudo-randomized odd-ball sequence of 80% standard and 20% deviant presentations with an inter-stimulus interval of 800±500 ms, delivered monaurally via Sennheiser HD 428 headphones to both ears. The oddball paradigm is an experimental design procedure, in which a sequence of repetitive auditory stimuli are frequently interrupted by a deviant stimulus. Deviant stimuli are hidden in a rare occurrence issue amongst a series of more common standard stimuli. In this study, the Pure Tone stimulus had standard stimuli of 1kHz and deviant stimuli of 4kHz. Also, the CV stimulus had standard stimuli of (da) and deviant stimuli of (ba). The stimuli presented were calibrated at ear level using a KEMAR ear-and-cheek simulator (G.R.A.S. Sound and Vibration, 43AG) and a type 1 integrating sound level meter (Norsonic, nor140) (13). The tone and CV stimuli contrast were delivered separately and tested for two trails. Each trail consisted of 350 stimuli, i.e. 70 deviant stimuli and 280 standard stimuli. Thus, there were 140 deviant stimuli and 560 standard stimuli presented over the two trails. The order in which the stimuli where presented ensured that there were 3-5 standard stimuli between each deviant stimulus. There was no counterbalance for this study; that is, the 1000 Hz/da stimulus was always the standard, and the 4000 Hz/ba stimulus was always the deviant.

CAEP Recording
An event-related potential is the noninvasively measured brain response that is the direct result of a specific sensory, cognitive, or motor event. More formally, it is any stereotyped electrophysiological response to a stimulus. The CAEP is the ERP evoked by a dedicated auditory stimulus such as pure tones, words and so on. However, subjects were seated in a comfortable armchair in a soundproof chamber. They were instructed to ignore any interrupting sound and minimize blinking and muscle movements to reduce the eye blink and muscle movement artifacts. Recording was done twice, at approximately 35 minutes each. To ensure the continuation of passive listening conditions, written short stories were presented throughout the experiment. The recording was done at 500 Hz sampling rate, using the wireless electroencephalography (EEG)/ERP acquisition system (Enobio, Neuroelectric, Spain) (14). The recording device Enobio EEG/ERP provided an on-line filter. The on-line filter consisted of a band pass filter, with a pass band (2 Hz – 40 Hz) second-order Butterworth FIR.

The EEG/ERP acquisition system. Data were recorded from four Ag/AgCl electrodes (channels) mounted on Neoprene EEG caps located over the following scalp sites: three electrodes were located on the midline of the head (Fz, Cz & Pz) and one electrode was located at the left side of the brain (C3) (according to the modified International 10-20 System) (15). EEG activity from each electrode was recorded with the common mode sense active electrode and driven right leg passive electrode, which refers to the linked mastoid. Furthermore, the study involved passive listening conditions. Therefore, all the volunteers were trained to ignore the incoming auditory stimulus, stay awake, and focus on the reading materials provided to them.

EEG Data Analysis
After ERP data collection, the responses evoked by the standard and deviant stimuli for both stimulus types (Pure Tone and CV) first went through pre-processing to correlate the baseline drift and filtered off-line at 2-30 Hz using a second-order Butterworth FIR band pass filter. These evoked responses were averaged for each trial separately. Then, these average evoked responses were averaged another time, with other trials in a session. Some recording sessions contained more than two trials, and some sessions resulted in bad trials (corrupted by artifacts and noises). The averaged trials were taken from successful runs that were free from artifacts, noises, and had a clear evoked CAEP signals. This averaging process was performed separately for each electrode used. However, the standard average responses excluded responses to the stim-
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Holdout validation. Using a 25% holdout ratio for the test set, and 75% for the training set of the features.

The cross-validation process can be used to help develop robust classifiers and efficient diagnostic systems. It is mainly used in settings where the goal is prediction, and one wants to estimate how accurately a predictive model will perform in practice. Two types of cross-validation can be used to detect and prevent overfitting (22).

Therefore, in order to distinguish between the CAEP signals, both stimuli were contrasted to determine if there was a significant difference in the CAEP of both stimuli and for both groups (MG & CG). Five classification methods were used to learn, classify, and distinguish between the CAEP signals for both stimuli contrasts. K-nearest neighbor, classification trees (bagged decision tree), SVM, LDA, and NB were used in this work to compare the performance parameters of each classification system in classifying the CAEP signals (21).

The SVM used a kernel trick to transform the data points into a higher dimensional space, and then separated them by a hyperplane at a maximal margin. The KNN works to determine a testing sample's class by the majority class of the k-nearest training samples. LDA is a generalization of Fisher's linear discriminant, a method used in statistics, pattern recognition, and machine learning to determine a linear combination of features that characterizes or separates two or more classes of objects or events. Classification trees are used to predict the membership of cases or objects in the classes of a categorical dependent variable from their measurements on one or more predictor variables. The NB is a simple and efficient statistical method, which is based on Bayes' theorem classification trees (bagged decision tree).

The feature matrix generated from the successful feature extraction method was 320 × 15 elements for both types of stimuli. The matrix contains four features (RMS Hilbert, KolmogEnt, SampleEnt, and ApproxEnt), four stimulus types (1 kHz, 4 kHz, da and ba), four electrodes (Fz, Cz, Pz & C3) for five time intervals, which were P1, N1, P2, N2 & P3 intervals, and for 15 subjects’ CAEP response. Therefore, for a classification matrix was constructed consisting of 320×15 elements and by using 4-fold cross-validation and a 25% holdout ratio. The training matrix was 240×15 and the test matrix was 80×15. The test matrix was used to evaluate the classification accuracy, which is a good indicator of the human brain's responses to different auditory stimuli.

However, to classify the CAEP responses for both ethnic groups, a feature matrix generated from the successful feature extraction method was (640×15) elements. The matrix contains four stimulus types (1 kHz, 4 kHz, da and ba), four features (RMS Hilbert, KolmogEnt, SampleEnt, and ApproxEnt), four recording electrodes with five time CAEP response intervals, which were P1, N1, P2, N2 & P3 intervals, and repeated twice (one for Malay and the other for Chinese) multiplied by the number of participating subjects (15 for Malay and Chinese subjects of normal hearing). Therefore, the classification matrix consists of 640×15 elements by using 4-fold cross-validation. The training matrix was 480×15 and the test matrix was 160×15. The test matrix was used to evaluate the classification accuracy; classification accuracy is a good indicator of the human brain's responses to different auditory stimuli. The performance of the proposed classification algorithms was evaluated using well-known performance parameter (accuracy) for each tested group, which is defined as follows (23):

\[
\text{Accuracy} = \frac{\text{Number of correctly classified observation}}{\text{Number of total observation}}
\] (1)

RESULTS
The experiments were performed for both groups (MG & CG), and placed in the following sections. The all-averaged cleaned CAEP responses for the tone stimulus (1 kHz stimulus) are shown in Figure 2 for both groups (MG & CG). Furthermore, a sample of the average ERP response before EMD and after EMD de-noising is shown in Figure 3 for the two tested groups. Also, Figure 3 shows the frequency component of the cleaned EEG late latency response of the ERP signal for the two tested groups. It clearly shows how the EMD technique cleaned the high frequency artifacts.
CAEP Components
The results of the averaged amplitudes and latency values were optioned from the CAEP waveforms for the successful subjects for each group. A sample of the late latency response of ERP waveforms at the Cz electrode, in both contrast stimuli for the MG group and CG group are shown in Figure 4 and Figure 5, respectively. Figure 4 demonstrates a sample of Malay subjects responses towards both sets of auditory stimuli. Moreover, Figure 5 shows a sample of Chinese subjects responses towards both sets of auditory stimuli. Table 1 indicates the mean and SD measurements of the CAEP late latency waveform amplitudes (in micro volt) for the MG & CG groups. These results corresponded to both auditory stimuli and for all CAEP components at Fz, Cz, Pz, and C3 electrodes. Moreover, Table 1 shows the mean and standard deviation (SD) measurements corresponding to both auditory stimuli for the latencies (in msec) of the CAEP components. These results were taken at the Fz, Cz, Pz, and C3 electrodes.

The average percentage of detectability of the CAEP components across volunteers were found to differ for the two test groups. P3 and N2 were the most detectable CAEP components, which appeared as 100% on pure tone and CV stimuli responses, respectively. However, this percentage collapsed across other CAEP components, in both study groups. P2 appeared in 82.2-83.8%, N1 68.5-73.1%, and finally P1 71.3-74.5% for pure tone and CV stimuli respectively, for the Malay group. In the Chinese group, P3 and N2 were also the most detectable CAEP components, which appeared in 100% on pure tone and CV stimuli responses, respectively.

However, this percentage collapsed also across other CAEP components, in both study groups. P2 appeared in 76.5-82.5%, N1 69.5-75.5%, and finally P1 66.5-68.5% for pure tone and CV stimuli respectively, which had the least score for percentage.

However, a t-test was used to distinguish the significantly affected CAEP component that was evoked by the auditory stimulus used on Malay normal hearing subjects. The t-test results were as follows:

A- Malay group, the test shows a significant effect (value) in the Fz electrode the amplitude of some of the CAEP components had: for CV stimulus; P1 (T= -3.7065, p=0.0009) and P2 (T= -2.186, p=0.0215). Moreover, for the latency: P1 (T= -2.0447, p=0.0288) in CV stimulus. However, there was no significant effect (value) for the pure tone stimulus for both auditory stimulus.

In the Cz electrode, the amplitude of some of the CAEP components shows a significant effect: for CV stimulus; P1 (T= 3.8146, p=0.0003) and N2 (T= -1.9999, p=0.0278). Moreover, in the pure tone stimulus for the amplitude of the CAEP component: P1 (T= 1.8929, p=0.0364).

In the Pz electrode, the amplitude of some of the CAEP components showed a significant effect: for CV stimulus; P1 (T= -1.7583, p=0.0457) and P2 (T= -3.9179, p=0.0005), for latency P2 (T= 1.813, p=0.0424), N2 (T= 1.8793, p=0.0361), and also in the pure tone stimulus for the amplitude of the CAEP component, P2 (T= -2.4014, p=0.014).

Figure 3. The cleaned averaged EEG recorded signal (1-kHz stimulus, Cz, Malay & Chinese NH)
Figure 4. Average CAEPs waveforms for normal hearing subject (Malay subject) with stimuli presented at 85 dB in the passive – listening condition at Cz electrode:
The top row waveforms represented the average CAEPs waveforms evoked by pure tone stimuli. The bottom row waveforms represented the average CAEPs waveforms evoked by CV.
The left column represented the CAEP waveforms evoked by standard stimuli, and the right column represented the CAEP waveforms evoked by deviant stimuli.

Figure 5. Average CAEPs waveforms for normal hearing subject (Chinese subject) with stimuli presented at 85 dB in the passive – listening condition at Cz electrode:
The top row waveforms represented the average CAEPs waveforms evoked by pure tone stimuli. The bottom row waveforms represented the average CAEPs waveforms evoked by CV.
The left column represented the CAEP waveforms evoked by standard stimuli, and the right column represented the CAEP waveforms evoked by deviant stimuli.
<table>
<thead>
<tr>
<th>Stimulus Groups</th>
<th>TONE stimuli (mean±SD)</th>
<th>CV stimuli (mean±SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrode Fz</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amplitude</td>
<td>0.72±0.42</td>
<td>0.53±0.32</td>
</tr>
<tr>
<td>Latency</td>
<td>84.4±17.1</td>
<td>82.9±12.2</td>
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<tr>
<td>N1</td>
<td>1.0±0.54</td>
<td>0.73±0.49</td>
</tr>
<tr>
<td>Latency</td>
<td>134.5±41.8</td>
<td>132.9±41.7</td>
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<tr>
<td>P2</td>
<td>0.74±0.27</td>
<td>0.67±0.48</td>
</tr>
<tr>
<td>Latency</td>
<td>189.3±26.1</td>
<td>181.5±18.0</td>
</tr>
<tr>
<td>N2</td>
<td>1.92±0.94</td>
<td>1.25±0.59</td>
</tr>
<tr>
<td>Latency</td>
<td>252.0±10.4</td>
<td>248.6±14.0</td>
</tr>
<tr>
<td>P3</td>
<td>3.61±0.98</td>
<td>3.46±0.87</td>
</tr>
<tr>
<td>Latency</td>
<td>325.9±15.6</td>
<td>323.4±10.1</td>
</tr>
<tr>
<td>Electrode Cz</td>
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</tr>
<tr>
<td>P1</td>
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<td></td>
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<tr>
<td>Amplitude</td>
<td>0.61±0.22</td>
<td>0.23±0.12</td>
</tr>
<tr>
<td>Latency</td>
<td>85.7±14.4</td>
<td>85.4±20.1</td>
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<tr>
<td>N1</td>
<td>0.51±0.11</td>
<td>0.41±0.13</td>
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<tr>
<td>Latency</td>
<td>147.7±27.1</td>
<td>144.0±29.4</td>
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<tr>
<td>P2</td>
<td>0.46±0.12</td>
<td>0.23±0.11</td>
</tr>
<tr>
<td>Latency</td>
<td>195.2±21.4</td>
<td>189.4±22.0</td>
</tr>
<tr>
<td>N2</td>
<td>1.96±0.88</td>
<td>1.56±0.75</td>
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<tr>
<td>Latency</td>
<td>252.1±10.7</td>
<td>254.1±13.3</td>
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<tr>
<td>P3</td>
<td>3.61±1.99</td>
<td>3.01±1.13</td>
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<tr>
<td>Latency</td>
<td>325.7±15.1</td>
<td>327.4±18.3</td>
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<td>Electrode Pz</td>
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<td>P1</td>
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<tr>
<td>Amplitude</td>
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<td>Latency</td>
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<tr>
<td>N1</td>
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<tr>
<td>Latency</td>
<td>136.8±13.2</td>
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</tr>
<tr>
<td>P2</td>
<td>0.68±0.20</td>
<td>0.61±0.17</td>
</tr>
<tr>
<td>Latency</td>
<td>181.3±31.8</td>
<td>179.8±22.3</td>
</tr>
<tr>
<td>N2</td>
<td>1.76±0.58</td>
<td>1.26±0.59</td>
</tr>
<tr>
<td>Latency</td>
<td>250.9±19.1</td>
<td>244.0±15.4</td>
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<tr>
<td>P3</td>
<td>2.41±0.64</td>
<td>2.07±0.83</td>
</tr>
<tr>
<td>Latency</td>
<td>327.6±21.7</td>
<td>320.5±16.6</td>
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<tr>
<td>Electrode C3</td>
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<tr>
<td>P1</td>
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<tr>
<td>Amplitude</td>
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<td>0.51±0.29</td>
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<tr>
<td>Latency</td>
<td>82.4±35.3</td>
<td>82.2±37.4</td>
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<tr>
<td>N1</td>
<td>0.58±0.35</td>
<td>0.40±0.28</td>
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<tr>
<td>Latency</td>
<td>139.8±29.6</td>
<td>146.1±38.3</td>
</tr>
<tr>
<td>P2</td>
<td>0.39±0.15</td>
<td>0.21±0.10</td>
</tr>
<tr>
<td>Latency</td>
<td>185.2±30.0</td>
<td>195.8±21.9</td>
</tr>
<tr>
<td>N2</td>
<td>1.83±0.53</td>
<td>1.60±0.44</td>
</tr>
<tr>
<td>Latency</td>
<td>250.9±11.0</td>
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<tr>
<td>P3</td>
<td>2.93±0.87</td>
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</tr>
<tr>
<td>Latency</td>
<td>330.6±15.2</td>
<td>331.6±16.2</td>
</tr>
</tbody>
</table>

SD: standard deviation; MG: Malay group; CG: Chinese group
The C3 electrode showed a minimum statistical effect for the CAEP components. Only the amplitude of P1 showed a significant effect (T= -2.1224, p=0.0219) in CV stimulus and a significant effect in latency for N2 (T= -2.0654, p=0.02412) in pure tone stimulus.

B- Chinese subjects, the test showed a significant effect (value) in the Fz electrode for the amplitude of some of the CAEP components for CV stimulus, N1 (T= -2.5954, p=0.0105) and latency, P1 (T= -2.171, p=0.0263). Moreover, in the pure tone stimulus for the amplitude of the CAEP component, P1 (T= -3.6115, p=0.0012), N1 (T= -2.1068, p=0.0341), N2 (T= -4.2626, p=0.0003), and for latency, P1 (T= -2.2346, p=0.0226), N2 (T= 2.7401, p=0.0067).

In the Cz electrode, the amplitude of some of the CAEP components showed a significant effect for CV stimulus only N1 (T= -1.9571, p=0.0346). Moreover, in the pure tone stimulus the amplitude of the CAEP component: P1 (T= -2.2629, p=0.02), N2 (T= 3.2014, p=0.0024) and for latency P1 (T= 1.8603, p=0.0437), P2 (T= 1.8915, p=0.0378), N2 (T= 2.4836, p=0.0118).

In the Pz electrode, the amplitude of some of the CAEP components showed a significant effect for CV stimulus, P1 (T= -3.6796, p=0.0025), P2 (T= -1.8247, p=0.044), and N2 (T= -2.6089, p=0.0121). No significant effect were shown for the latency. Moreover, in the pure tone stimulus, the amplitude of the CAEP component had P1 (T= -3.4119, p=0.0029), P2 (T= -1.8108, p=0.0477) and N2 (T= -1.8731, p=0.0386), and for latency, P1 (T= 2.7739, p=0.0098), N2 (T= 2.8457, p=0.0061).

In the C3 electrode, the amplitude of some of the CAEP components showed a significant effect as follows: for CV stimulus, P2 (T= -1.8789, p=0.0434), N2 (T= -2.4971, p=0.0148), and P3 (T= -2.3259, p=0.00167). A significant effect in the pure tone stimulus was shown in the amplitude of the CAEP component, P1 (T= -4.912, p=0.0005), P2 (T= -2.4696, p=0.0183) and N2 (T= -1.8705, p=0.0388), and for latency only N2 (T= 2.3495, p=0.0155).

ANOVA test

A two-way ANOVA test was conducted to outline the significant differences in the averaged amplitudes and latencies of the CAEP components due to the auditory stimulus used in both tested subjects groups (MG & CG). Also, the two-way ANOVA was used to investigate the significant differences of the CAEP responses to the auditory stimulus between the normal hearing sensitivity of Malay and Chinese subjects (MG & CG groups). A two-way ANOVA was performed as follows: subject group (SG) (normal hearing MG and normal hearing CG); stimulus type (ST) (pure tone and CV) with repeated measures on amplitudes and latencies for CAEP components (P1 N1, P2, N2, and P3). The results of the two-way repeated measures ANOVA were as follows:

A- The ANOVA test showed a significant effect (value) in the amplitude of some of the CAEP components as in the Fz electrode with the SG: P1 (F=4.902, p=0.031), P2 (F=4.581, p=0.036), N2 (F=8.884, p=0.004), and P3 (F=4.351, p=0.041), and ST: P1 (F=5.167, p=0.027).

In the Cz electrode, N1 (F=85.15, p<0.001), P2 (F=11.016, p=0.001), N2 (F=329.66, p<0.001) and P3 (F=9.957, p=0.002). ST: P2 (F=3.996, p=0.049). SG×ST, N2 (F=8.834, p=0.004).

In the Pz electrode, N1 (F=84.266, p<0.001), P2 (F=5.455, p=0.023), N2 (F=216.11, p<0.001) and P3 (F=21.095, p<0.001). ST: P2 (F=4.222, p=0.044). SG×ST, N1 (F=5.116, p=0.027).

In the C3 electrode, N1 (F=110.00, p<0.001), P2 (F=17.257, p<0.001), N2 (F=296.2, p<0.001), and P3 (F=21.044, p<0.001). SG×ST, P3 (F=4.65, p=0.034).

B- The ANOVA test showed a significant effect (value) in the latency of some of the CAEP components as in the Fz electrode with; the SG: N1 (F=5.178, p=0.026), P2 (F=5.563, p=0.021), N2 (F=32.841, p<0.001) and P3 (F=42.657, p<0.001). SG×ST, N2 (F=21.53, p<0.001) and P3 (F=14.55, p<0.001).

In the Cz electrode, P1 (F=12.181, p=0.001), N1 (F=17.626, p<0.001), P2 (F=8.206, p=0.005), N2 (F=54.334, p<0.001) and P3 (F=68.517, p<0.001). ST: P3 (F=8.019, p=0.006). SG×ST, N2 (F=24.8, p<0.0001) and P3 (F=20.02, p<0.001).

In the Pz electrode, N1 (F=5.507, p=0.022), P2 (F=11.431, p=0.001), N2 (F=26.266, p<0.001), and P3 (F=36.942, p<0.001). ST: P3 (F=7.056, p=0.01). SG×ST, P2 (F=11.5, p=0.001), N2 (F=28.98, p<0.001), and P3 (F=12.37, p=0.001).

In the C3 electrode, N1 (F=8.686, p=0.004), P2 (F=4.262, p=0.043), N2 (F=15.278, p<0.001), and P3 (F=7.327, p=0.008). However, no significant effect was found elsewhere.

Classification of CAEP response to both stimuli and for both testing groups

Five classification methods were used to learn, classify, and distinguish between the CAEP signals for both stimuli contrasts. KNN, classification trees (bagged decision tree), SVM, LDA, and NB were used in this work to compare the accuracy performance of each classification system in classifying the CAEP signals. The CAEP components with its features (as in section 3.3.1) were classified using SVM with radial basis function (RBF) kernel, LDA, KNN with k = 1, classification trees (bagged decision tree), and NB classifiers for both cross-validation methods. The performance parameter (accuracy) for both cross-validation methods was obtained using Eq. (1). Table 2 shows the accuracy for both tested groups (MG & CG).

By using Eq.(1), the performance parameter (accuracy) for both cross-validation methods was obtained. Table 3 shows the accuracy for classification of ethnic groups.
DISCUSSION

This section discusses the late CAEP components that were recorded from the healthy Malay SG and individual Chinese speaker population, in which both groups had normal hearing abilities. In this study, the CAEPs were recorded, investigated, and analyzed systematically from (15 Malay and 15 Chinese) male adults with normal hearing in response to tone bursts of 1 and 4 kHz and consonant-vowel speech stimuli of /ba/ and /da/ at an intensity of 85 dB SPL. Both stimuli contrasts were presented in an oddball paradigm in passive listening condition. The results illustrated and presented that:

General Finding

The results in Table 1 show that the average peak amplitude of the CAEP components stimulated by pure tone and CV stimuli for electrode Cz was greater than for other electrodes used for

<table>
<thead>
<tr>
<th>CLASSIFIER</th>
<th>STIMULI</th>
<th>K-fold</th>
<th>Hold-out</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CV</td>
<td>Pure Tone</td>
<td>CV</td>
</tr>
<tr>
<td></td>
<td>Accuracy</td>
<td></td>
<td>Accuracy</td>
</tr>
<tr>
<td>KNN</td>
<td>CV</td>
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<td>19</td>
</tr>
<tr>
<td></td>
<td>Pure Tone</td>
<td>17</td>
<td>143</td>
</tr>
<tr>
<td></td>
<td>Accuracy</td>
<td>284/320=0.8875</td>
<td>275/320=0.8593</td>
</tr>
<tr>
<td>SVM</td>
<td>CV</td>
<td>142</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>Pure Tone</td>
<td>15</td>
<td>145</td>
</tr>
<tr>
<td></td>
<td>Accuracy</td>
<td>287/320=0.8968</td>
<td>285/320=0.8906</td>
</tr>
<tr>
<td>TREE</td>
<td>CV</td>
<td>138</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td>Pure Tone</td>
<td>29</td>
<td>131</td>
</tr>
<tr>
<td></td>
<td>Accuracy</td>
<td>269/320=0.8406</td>
<td>265/320=0.8281</td>
</tr>
<tr>
<td>LDA</td>
<td>CV</td>
<td>137</td>
<td>23</td>
</tr>
<tr>
<td></td>
<td>Pure Tone</td>
<td>30</td>
<td>130</td>
</tr>
<tr>
<td></td>
<td>Accuracy</td>
<td>267/320=0.8343</td>
<td>262/320=0.8187</td>
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<tr>
<td>NB</td>
<td>CV</td>
<td>128</td>
<td>32</td>
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<tr>
<td></td>
<td>Pure Tone</td>
<td>30</td>
<td>130</td>
</tr>
<tr>
<td></td>
<td>Accuracy</td>
<td>258/320=0.8062</td>
<td>260/320=0.8125</td>
</tr>
</tbody>
</table>

KNN: K-Nearest Neighbor; SVM: support vector machines; LDA: Linear Discriminant Analysis; NB: naive bayes; CV: consonants vowels; MG: Malay group; CG: Chinese group

Table 2. The performance parameters of classifiers for both tested groups (MG & CG)

<table>
<thead>
<tr>
<th>CLASSIFIER</th>
<th>ETHNIC GROUP</th>
<th>MALAY (MG)</th>
<th>CHINESE (CG)</th>
<th>MALAY (MG)</th>
<th>CHINESE (CG)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>K-fold</td>
<td>Hold-out</td>
<td>K-fold</td>
<td>Hold-out</td>
<td></td>
</tr>
<tr>
<td>SVM</td>
<td>cv</td>
<td>260/268</td>
<td>52/58</td>
<td>262/267</td>
<td></td>
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<tr>
<td></td>
<td>Accuracy</td>
<td>528/640=0.825</td>
<td>529/640=0.8265</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TREE</td>
<td>cv</td>
<td>255/257</td>
<td>63/67</td>
<td>257/253</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Accuracy</td>
<td>512/640=0.8000</td>
<td>510/640=0.7968</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LDA</td>
<td>cv</td>
<td>256/251</td>
<td>64/66</td>
<td>254/259</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Accuracy</td>
<td>507/640=0.7921</td>
<td>502/640=0.7843</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NB</td>
<td>cv</td>
<td>244/238</td>
<td>76/79</td>
<td>241/233</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Accuracy</td>
<td>482/640=0.7531</td>
<td>474/640=0.7406</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

KNN: K-Nearest Neighbor; SVM: support vector machines; LDA: Linear Discriminant Analysis; NB: naive bayes; CV: consonants vowels; MG: Malay group; CG: Chinese group

Table 3. The performance parameter of classification of the ethnic groups
both testing groups. The CAEP amplitude in the vertex midline (Cz) was the largest because this site contains many sensory, cognitive, and control nerves. The results of CAEP testing revealed that all average deviant (4 kHz and ba) responses produced lower amplitude activation in accordance with both sets of auditory stimuli and for both groups (MG & CG), as stimulus frequency increased. This decrease is attributed to two different effects. First, a larger portion of the basilar membrane is activated by a low-frequency tone because the wave travels from the basal to the apical cochlear turn, compared with a high-frequency tone for which the traveling wave is restricted to the basal turn. It has been suggested that there is some cortical representation of basilar membrane traveling wave properties resulting in larger cortical responses for low frequency tones. In addition, Table 1 points out that the mean and SD of the CAEP amplitude components evoked by a pure tone stimulus were higher than that evoked by a CV. Consonants Vowels, stimuli had some tunes larger than the pure tone stimuli.

In addition, the results of CAEP testing revealed that the amplitudes of CAEP components for the Chinese group were lower than those of the Malay group. This and the prolongation in timing of the latencies could be an indicator of a hearing impairment in this group. Most Chinese subjects are exposed to high amplitudes and frequency tones due to the nature of their language. The Chinese language, called the Mandarin language, contains more than 7000 different sounds. Modern Standard Mandarin Chinese has about 7000 commonly used characters (excluding 2000 rare ones).

Measurement of the Cortical Auditory Evoked Potentials Components

The N1 and P1 components

N1 and P1 components are the early brain responses to a stimulus, they are very complex, and may be influenced by several brain regions, including the frontal cortex, so the primary auditory cortex may be one of several contributors to the maturational aspects of N1 and P1. N1 is likely to reflect integrative and facilitative processes, sound detection, orienting, and selective attention, specifically attentional resources allocated to a relevant stimulus. The results discovered that low-appearing percentages (the lowest appearing percentage of the CAEP components) for the early brain response to auditory stimuli were the N1 and P1 from CAEP components. Also, the average mean amplitude of the auditory N1 and P1 were attenuated in the Chinese group compared with the Malay group, for the same reasons reported above.

The N2 and P2 components

P2 is a distinct wave following the N1 wave at the anterior and central scalp sites. It is shown that the appearance of auditory CAEP component P2 is the second largest appearing percentage. The percentages for the pure tone stimulus and CV stimulus respectively were (85.5-89.5%) for the Malay group and (76.5-82.5%) for the Chinese group. From the result, it is shown that the percentage of appearance for the pure tone stimulus was greater in comparison with the CV stimulus. Because this component is larger for stimuli containing target features, and this effect is enhanced when the targets are relatively infrequent, this study had a deviant stimulus, which appears in 0.2 probability in a single run. In this sense, the anterior P2 wave is similar to the P3 wave. However, the anterior P2 effect occurs only when the target is defined by fairly simple stimulus features. Also, from the above results, N2 was elicited in all groups and it had 100% appearance in both standard and deviant stimuli. This component is larger for less frequent targets, and it is thought to be a sign of the stimulus categorization process. The amplitude and latency of the P2 and N2 are pointed out in this study as somewhat larger in the Chinese group in comparison with the other group. This was for the same reasons listed above.

The P3 component

P3 was elicited in all groups and it had 100% appearance in both standard and deviant stimuli, which appears clearly at the Cz electrode. P3 is usually recorded from electrodes located over the centro-parietal regions of the scalp (such as Cz and Pz sites). One explanation why P3 was the most dominant component in this study is that it is best elicited when stimuli are delivered in an oddball paradigm manner. Furthermore, there was another aspect worth consideration, which is the great extent in amplitude and latency of CV stimuli response, in which P3 was evoked by speech sound stimuli. It appears that different attentional processes were engaged in response to speech sound stimuli compared with pure tone stimuli. In the Chinese group, for the P3 component results, it had large values for latency and almost for amplitude compared with the Malay group. P3 amplitude is larger when subjects devote more effort to a task. P3 amplitude gets larger as the auditory stimulus probability gets smaller and confusing due to somewhat of an impairment of hearing. Thus, if it is hard to hear the auditory stimulus for the Chinese group, this might increase P3 amplitude by encouraging subjects to devote more effort for trying to hear the auditory stimulus.

The t-test results

P1 had the most significant effect in amplitude and latency due to stimulus interaction changes between the standard and the deviant stimuli in pure tone and CV stimuli. This is due to the fact that the P1 component grew by giving more attention to auditory stimuli, or by increasing the stimulus interval. The P1 response is an obligatory response, meaning that this component is essentially related to the stimulus characteristics and not to the predictions of the auditory brain system by the listener. Similarly, N2 also had the most significant effect in amplitude and latency due to stimulus interaction changes between the standard and the deviant stimuli in pure tone and CV stimuli. This is due to the fact that the N2
The CAEP components in different human ethnic groups, Ibrahim et al.

The CAEP components in different human ethnic groups, Ibrahim et al.

The results show that the t-test results for the amplitudes and latencies of the CAEP components in both stimulus types from the Malay normal hearing group, in which the interaction between the standard and deviant stimuli were more statistically significantly affected in comparison with the CV stimuli for all electrodes used. The pure tone stimuli have a wide range of frequency band between its standard and deviant stimuli in comparison with those of the CV stimulus. Thus, this will produce high changes in the CAEP responses and will therefore lead to having a statistically significant effect (4, 24, 25). The P1, N1, and N2 were the most significantly affected in amplitude due to both stimuli in all electrodes used; also P1 and N2 had significant effects in latency due to both stimuli in almost all electrodes used. However, other CAEP components had less significant effects between the standard and deviant stimuli for both stimuli and in the four electrodes used.

However, P3 has a very small significant effect on both amplitude and latency and for both stimulus types (pure tone and CV). The P3 waves were extracted in the decision-making process. Also, P3 is an endogenous potential because its appearance is not related to the physical property of stimuli, but is related to a human’s reaction to the stimuli (27, 30). However, in this study, the CAEP responses were recorded from the passive protocol, where action responses are not required. Thus, this action protocol often does not show a significant effect for P3 components.

The Two-way ANOVA test
The results show that the most affected electrodes due to the ANOVA test were the Cz and Pz electrodes. These electrodes were mostly statistically significant (p<0.05) in comparison with the other electrodes used (35, 36). The P2, N2 & P3 CAEP components were the most affected CAEP components. They were 100% statistically significant in amplitudes and latencies in all electrodes used for the SG. The N1 component was a highly statistically significant indicator in this test in amplitudes and latencies, but it was not a statistically significant indicator in the amplitude of the Fz electrode. However, the statistically significant indicator reduced in P1; it shows a statistically significant indicator only on Fz electrode for amplitudes and on the Cz electrode for latencies. The SG (MG & CG) had full or very clear statistically significant effects. Moreover, the SG (MG & CG) showed a statistically significant indication in all electrodes used and for most of the CAEP components. However, the interaction factor of the ANOVA test had a lower statistically significant indicator in most of the electrodes used and a very low (rare) statistically significant indicator for stimulus factors in most of the electrodes used. In general, the ANOVA test had a major statistical significance in the amplitude of the CAEP component, whereas in the latency there was minor statistical significance for all electrodes used. The ANOVA results showed that there were highly significant differences between the SG (MG & CG) CAEP responses, which means that there were significant differences between the CAEP components (amplitudes and latencies) between the two tested groups. These differences come from the variety of the sounds in particular words in each tested group language. The ANOVA results assisted the hypothesis that the human brain produces different CAEP responses to each language in a separate manner, according to their language circumstances during learning of the native languages.

Classification Accuracy
Initially, we noticed from Table 3, that the accuracy of classifications (or classification performances) for the CG group was excellent and reached a high score for all classifier algorithms used, whereas the accuracy of classification (or classification performances) for the MG groups had lower classification performances in comparison with the classification performances of the CG group. This was seen for all classifier algorithms used. Chinese people the ability to understand and interpret more than 7000 different sound characters (excluding 2000 rare ones) (26). Therefore, their brains have been trained and have experience in a wide range of sounds. This type of brain could easily specify or recognize a desired target sound or a specific word.

The results listed in Table 2 draw a comparison of five different classification systems. The features extracted are the same but the classifiers used are different. Therefore, the algorithm proposed in this work, using SVM as classifiers, returned a better accuracy than the system that used trees (bagged decision tree), KNN, BN, and LDA classifiers. This is because the features extracted with non-linear feature extraction methods are more accurate and the structure of the classification algorithm depends on the RBF kernel threshold level design. In the same way, the features used in the other work combined with a SVM classification algorithm would lead to having worse accuracy (37, 38). The NB classifier had an accuracy of 78.88%, which was the lowest classification accuracy obtained in this study. This study provided an actual comparative study for classification of brain auditory responses in two different ethnic groups (MG & CG). As seen in the Table 3, the high correct classification accuracy in the SVM classifier using the non-linear features could
be recommended to be used in BCI systems and other systems that use brain signal classification applications. Moreover, because the CAEP responses were classified according to its ethnic group, this will help in developing efficient clinical applications, and for developing better aural rehabilitation techniques for both ethnic groups in the future.

The study concluded that the human language alters the hearing map in the brain (auditory mapping process). However, this study has a small sample size. Further analysis involving large databases should be performed in any future works. This study will help in developing an efficient clinical application, and for developing a better aural rehabilitation technique for both ethnic groups in the future.

Ethics Committee Approval: Ethics committee approval was received for this study from the ethics committee of the University of Malaya (No. 1045.22 with Research Grant UMRG RP016D-13AET).

Informed Consent: Written informed consent was obtained from patients who participated in this study.

Peer-review: Externally peer-reviewed.


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Conflict of Interest: The authors have no conflicts of interest to declare.

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