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Effects of Speech Phonological Features during Passive Perception on Cortical Auditory Evoked Potential in Sensorineural Hearing Loss

(Kesan Ciri Fonologi Pertuturan semasa Persepsi Pasif pada Korteks Auditori Rangsang Potensi dalam Kehilangan Pendengaran Sensorineural)

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ABSTRACT

The deficiency in the human auditory system of individuals suffering from sensorineural hearing loss (SNHL) is known to be associated with the difficulty in detecting of various speech phonological features that are frequently related to speech perception. This study investigated the effects of speech articulation features on the amplitude and latency of cortical auditory evoked potential (CAEP) components. The speech articulation features included the placing contrast and voicing contrast. 12 Malay subjects with normal hearing and 12 Malay subjects with SNHL were recruited for the study. The CAEPs response recorded at higher amplitude with longer latency when stimulated by voicing contrast cues compared to that of the placing contrast. Subjects with SNHL elicited greater amplitude with prolonged latencies in the majority of the CAEP components in both speech stimuli. The existence of different frequency spectral and time-varying acoustic cues of the speech stimuli was reflected by the CAEPs response strength and timing. We anticipate that the CAEPs responses could equip audiologist and clinicians with useful knowledge, concerning the potential deprivation experience by hearing impaired individuals, in auditory passive perception. This would help to determine what type of speech stimuli that might be useful in measuring speech perception abilities, especially in Malay Malaysian ethic group, for choosing a better rehabilitation program, since no such study conducted for evaluating speech perception among Malaysian clinical population.

Keywords: Consonant-vowel (CV); cortical auditory evoked potential (CAEP); electroencephalography (EEG); mismatch negativity (MMN); sensorineural hearing loss (SNHL)

ABSTRAK

Kekurangan dalam sistem auditori manusia terhadap individu yang mengalami kehilangan pendengaran sensorineural (SNHL) diketahui melalui kesukaran dalam mengesan pelbagai ciri ucapan fonologi yang sering berkait-rapat dengan persepsi pertuturan. Kajian ini mengetengahkan kesan ucapan artikulasi terhadap amplitud dan kependaman pada komponen potensi terbangkit auditori kortikal (CAEP). Ciri ucapan artikulasi termasuk kontras perletakan dan kontras suara. Seramai 12 individu normal tahap pendengaran dan 12 individu yang memiliki SNHL telah direkrut untuk kajian ini. Tindak balas CAEP terhadap isyarat kontras suara direkodkan pada amplitud lebih tinggi serta kependaman lebih lama berbanding isyarat kontras perletakkan. Individu yang memiliki SNHL menghasilkan amplitud lebih tinggi berserta kependaman lebih panjang dalam kebanyakan komponen CAEPs dan ini meliputi kedua-dua rangsangan ucapan. Kewujudan perbezaan spektrum frekuensi dan beza-masa isyarat akustik pada rangsangan ucapan dicerminkan oleh kekuatan tindak balas dan tempoh masa CAEPs. Kami menjangkakan bahawa tindak balas CAEPs dapat menyediakan pengetahuan yang berguna kepada pakar audiologi dan doktor dalam memahami pengurangan potensi yang dihidapi oleh individu persepsi auditori terjejas. Ini dapat membantu untuk menentukan apa jenis ransangan ucapan yang bersesuaian dalam menilai keupayaan persepsi ucapan, terutamanya dalam kalangan etnik Melayu di Malaysia seterusnya memilih program pemulihan yang lebih baik, kerana tidak ada kajian seumpama ini yang pernah dijalanlan untuk menilai persepsi ucapan dalam kalangan penduduk klinikal Malaysia.

Kata kunci: Elektroensefalografi (EEG); hilang saraf deria pendengaran (SNHL); konsonan-vokal (CV); korteks auditori rangsang potensi (CAEP); kenegatifan tak padan (MMN)

Introduction

Accurate speech perception within features of speech articulation through spoken language is essential for human to communicate during social interactions. The speech acoustic phonological features such as voice/voiceless distinction, place and manner of articulation provide a crucial complexity mapping mechanism which creates a stable neuronal representation in the human auditory system (Anderson et al. 2013; Korczak & Stapells 2010). The significant of speech perception for passive condition is evident in peoples suffering from sensorineural hearing loss (SNHL), whose impaired speech articulatory selectivity and discrimination contribute to the difficulty in understanding speech (Boothroyd 1993; Siti Zamratol-Mai Sarah et al. 2016; Oates et al. 2002; Wunderlich & Cone-Wesson 2001).

To date, degraded speech perception among people with SNHL is still remains unclear. Several investigators used cortical auditory evoked potential (CAEP) as a diagnostic tool to investigate how the brain processes phonologic features in speech signal. Components of CAEP constituting the neuronal linguistic processes are associated with words and sentences, depends entirely on the acoustic continuum so as to discriminate with the desired neural pattern of perception. Generally, measurements of CAEPs response strength (amplitude) and timing window (latency) can provide objective information in terms of auditory processing underlie speech perception in normal as well as in difficult-to-test patients (Arsenault & Buchsbaum 2015; Pratt et al. 2009; Schröder et al. 2014). Previous study elucidated that CAEPs testing could provide productive responses in assessing auditory pathway without requiring cooperation (passive) from the subjects (Agung et al. 2006).

Former studies used speech sound varied along the acoustic continuum of voice-onset-time (VOT) (Tremblay et al. 2003) and frequency spectral (Korczak & Stapells 2010) and reported different effects on CAEP components amplitude and latency. The present study extended the previous works by evaluating the amplitude and latency of CAEP components in SNHL subjects using Malay complex sound, i.e. CV tokens that differ in terms of their features of speech articulation. Earlier studies done by Wunderlich et al. (2001) used CV tokens /bae/ vs /dae/ and tonal stimuli to demonstrate the parallel effects found on the N1 and P2 amplitudes when both decreased in values as frequency increased. They concluded that there was close relationship between N1 and MMN and both reflected the tonotopicity of the auditory cortex. Oates et al. (2002) had highlighted the attenuation effects of CAEPs components on subjects with SNHL when they received the speech stimuli. Prolonged latency on late components (N2, P3) compared to earlier components (N1, MMN) was experienced by the subjects with SNHL. This indicated that the latency parameters were more sensitive towards evaluating decreased audibility compared to the response strength. For these reasons, morphology of CAEPs is thought to reflect the functional integrity of human auditory pathways that depends with phonologic features of speech in performing speech perception.

(Tremblay et al. 2003) discovered the implication of VOT on CVs tokens involving voice/voiceless phonemes. They presented speech tokens at 10 ms increments along a /ba/-/pa/ VOT continuum to young and older adults. They found that N1 and P2 latencies were prolonged with VOT durations. Difficulty was found in discriminating longer time-varying acoustic cues in speech language. More clinical application was carried out by Schröder et al. (2014). They justified the efficacy of CAEPs response in evaluating dysfunctionality of the brain's early auditory processing system in subjects with misophonia. The finding showed the diminished N1 component to oddball stimuli, thus suggested an underlying neurobiological deficit in misophonia patient.

The mismatch negativity (MMN) response evokes when a constant train of identical stimuli with 'new' afferent infrequent mismatching stimuli was presented to an individual's auditory system. This response processes automatically when incoming stimuli is perceived to a sensory memory trace of preceding stimuli which is not only sensitive to task-relevant condition, but also when the subjects merely ignore the stimulus stream for different task as in passive listening condition (Luck 2005; Näätänen 1995; Steinhauer 2014). The mainstream interpretation of MMN usage in clinical application begun in the late 1990s when it provided a potential means for measuring possible auditory perception and sensory-memory anomalies (Näätänen et al. 1993). Previous researchers concluded that the human auditory system elicited greater brain response towards speech CV stimuli compared to tonal stimuli as reflected in higher MMN and P3a amplitude values (Jaramillo et al. 2001; Tavabi et al. 2009). Former studies also proposed that the enlargement of MMN amplitudes in native speakers with two non-native speaker groups indicates the activation of native-language phonetic prototypes (Picton et al. 1995; Ylinen et al. 2006). As per objective, the current study only included the native Malaysian Malay ethnic groups where Malay CV speech tokens were presented and we hypothesized that the MMN will be elicited due to the present of language memory trace (Näätänen 2001; Ylinen et al. 2006).

The major aim of the current study was to employ the effects of CAEP components as a measure of voice/voiceless distinction against place of articulation involving CV stimuli during passive listening between healthy normal and individuals suffering from SNHL. Collectively, these electrophysiological measures may be well explained on the differences happened during preconscious speech processes at higher levels in the brain, besides showing the direct relationship between the acoustic signal and the perceived phoneme (Abbs & Sussman 1971; Stapells 2002). We hypothesized that since these two sounds are phonetically and spectrally distinct, they may evoke CAEPs with different morphological responses and might provide us information on how auditory pathway perform discriminant mechanism during passive perception between each of these different speech sounds since the goal is to apply in everyday life.

For the last six years, depth exploration was done by Korczak and Stapells (2010) to understand the effects of three articulatory features of speech including vowel-space contrast, place of articulation and voice/voiceless discrimination on normal subjects. They reported that the brain may have a difficult task in discriminating consonant stimuli as compared to vowel stimuli due to rapidly transition of formant frequencies. Thus, recent development extends the core idea to create more beneficial direction on the significance of CAEP components in discriminating various speech of articulation especially in individuals suffering from SNHL for better knowledge regarding electrophysiological correlates of speech perception. To date, there is no study to evaluate the passive neuronal activation involving SNHL population between the phonological features of speech sound. The study focuses on the CAEP data for Malaysian population since no such study is available for evaluating speech perception among Malaysians. Therefore, the aims of the present study were to investigate whether, CAEP components show different pattern in response to latencies and amplitudes between speech stimuli; and MMN was appear and elicited in response to Malay CV stimuli to disclose any neuropathological changes in the auditory pathway.

METHODS

PARTICIPANTS

The study involved two groups of subjects: First, 12 right-handed Malaysian male adult subjects (fluent Malay-speakers) between 20 and 45 years of age (mean age=32.2 year, SD=6.9 years) having bilateral SNHL for more than 6 months and second 12 right-handed Malaysian male adult subjects (fluent Malay-speakers) between 20 and 45 years of age (mean age=28.7 year, SD=5.4 years) with normal hearing sensitivity which served as the control group. Normal hearing participants recruited were healthy subjects with no past history of otological, psychological or neurological complications and without any speech or hearing disorders. All participants involved in this study were tested at the Department of Otorhinolaryngology (ENT), University Malaya Medical Centre (UMMC) using the routine pure tone audiometry (PTA) measurement. Written informed consent was obtained from all participants. Medical ethics clearance was approved by the Medical Ethics committee, University Malaya Medical Centre (Reference No. 1045.22). Subjects with normal hearing (NH) showed normal pure-tone audiological presentation of 15 dB hearing level (HL) or better between 250 and 8000 Hz for both ears. The subjects with SNHL suffered from mild to moderate hearing loss level bilaterally based on the average of their 500 to 2000 Hz pure-tone thresholds (PTA≥35 dB HL and <74 dB HL). To evaluate the cognitive state, attention, mental and memory capabilities as well as language deprivation of selected participants, a simple Mini Mental State Examination (MMSE) was conducted before the recording session (Ali et al. 2013; Folstein et al. 1975)

STIMULUS PRESENTATION

The study selected two sets of speech articulation features which are voiced/voiceless distinction *ba* versus *da* (/ba/-/da/) and place of articulation features *ba* versus *pa* (/ba/-/pa/). These consonant-vowel (CV) speech stimuli respectively were presented at 80 dB sound pressure level (SPL) to accommodate both degree of SNHL (Korczak & Stapells 2010). The natural digitizing speech tokens were produced by a female Malaysian Malay native speaker and the speech tokens were recorded at 44,100 Hz sampling frequency. The tokens were edited into 250 ms in duration by removing the initial vibration of the vocal cord portion, the end part of the steady state vowel and windowing the offset.

The CVs stimuli were played at pseudorandomized oddball paradigm, which consisted of standard stimuli having 0.8 occurrence probability and the deviant stimuli having 0.2 occurrences. For each set of speech stimuli, both CVs sounds were presented as standards and deviants in separate runs with onset inter-stimulus intervals (ISI) of 800 ± 200 ms duration. This randomized slight interval reduces the temporal prediction probability of the incoming auditory stimulus for both standard and deviant stimuli. They were delivered via Sennheiser HD 428 closed circumaural headphones to both ears and were calibrated at ear level using CR: 160 series Cirrus Optimus red sound level meter to obtain the desired SPL level (Anderson et al. 2013). The study was done in passive listening condition and tested for two runs with a few minutes of rest between runs. In each run, the speech CVs tokens consisted of 400 total stimuli; i.e. 320 standard stimuli and 80 deviant stimuli, in such conditions that 2-6 standard stimuli were presented between each deviant stimulus. Thus, each stimulus contrasts yielding a total of 800 stimuli containing 160 deviant stimuli and 640 standard stimuli replicated over the two runs. Counterbalanced paradigm was implemented in this study where one token acted once as a deviant in one run and once as standard in another run for each set of CVs stimuli respectively (Duncan et al. 2009; Korczak & Stapells 2010). Figure 1 shows the spectrogram of three associated CV tokens that were used in the present study.

ELECTROPHYSIOLOGICAL CORTICAL AUDITORY EVOKED POTENTIAL (CAEP) RECORDINGS

The electroencephalography (EEG) activity of the CAEPs was recorded at a sampling frequency of 500 Hz from eight EEG electrode channels with a wireless EEG device (EnoBio, Neuroelectrics, Spain) (Ruffini et al. 2007, 2006). Ag/AgCl electrodes were mounted on a Neoprene EEG cap. Electrodes were placed at the positions of F_Z, C_Z, P_Z, C_4, T_4, C_3, T_3 and F_{PZ}. The active Common Mode Sense (CMS) electrode and passive Driven Right Leg (DRL) electrode were served as reference and ground respectively where both were connected to two electrodes located at the right mastoid. A standard computer equipped with Neuroelectrics NIC 1.3 software (EEG data collection) and MATLAB R2013a (stimulus presentation and analysis) software were designed and used for the electroencephalographic data collection and post-processing analysis. All the participants were instructed to sit quietly and comfortably in a sound proof chamber. Prior to electrophysiological recording, all the subjects were asked to reduce artifacts of the eye blinks

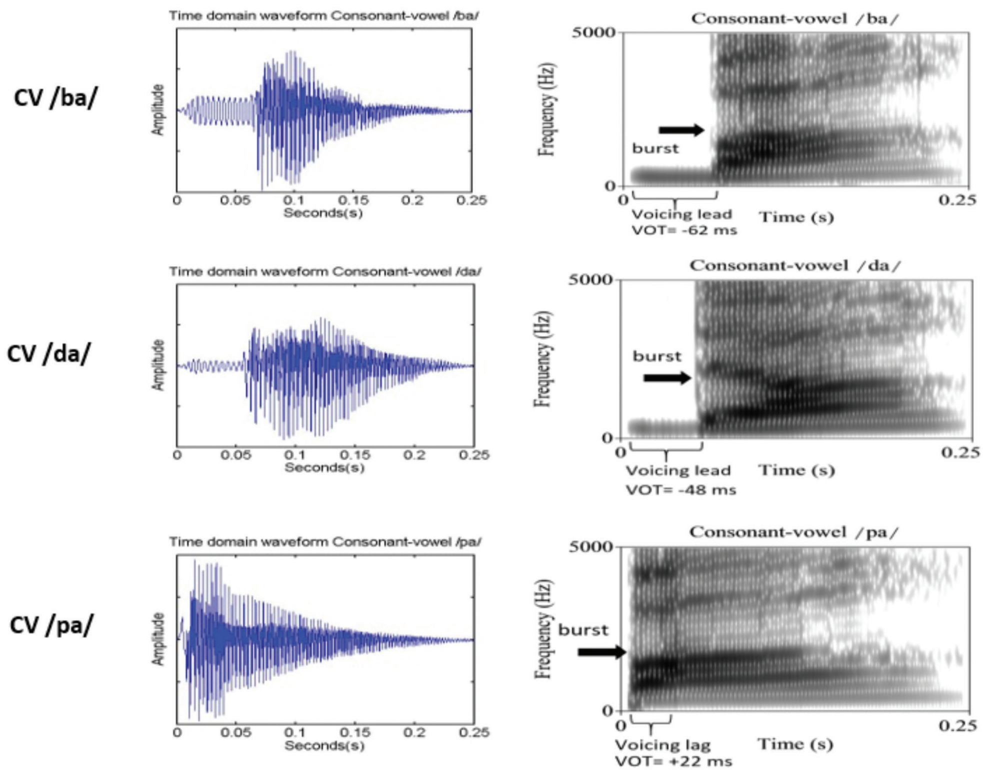

FIGURE 1. Comparison of spectrogram for the three CV syllables. /ba/: 292 Hz (F0), 740 Hz (F1), 1481 Hz (F2), 3228Hz (F3), 4310 Hz (F4); /da/: 291 Hz (F0), 759 Hz (F1), 1795 Hz (F2), 3155 Hz (F3), 4254 Hz (F4); /pa/: 344 Hz (F0), 928 Hz (F1), 1523 Hz (F2), 3478 Hz (F3), 4437 Hz (F4)

and muscle movement. Since the study involved passive listening conditions, all volunteers were informed to ignore the incoming auditory stimulus, stay awake and focused on the Malay reading material that was provided to them. Each set of experiments was done in about 30 min per run.

CORTICAL AUDITORY EVOKED POTENTIAL (CAEP) WAVEFORMS MEASUREMENT AND DATA ANALYSIS

After completion of the CAEP data recording, the evoked response was pre-processing offline to remove artifacts, correct baseline drift and filter the power supply. These processes were done using a notch filter at 50 Hz and a Butterworth band-pass filter of 1-45 Hz. For each set of experiments, the two successive runs of each group's standard and deviant stimuli were averaged. Due to the implementation of the counterbalance paradigm in this study, the evoked response obtained from the counterbalance standard and deviant stimuli were summed and averaged with the previous session. Finally, each set of stimulus presentation will produce evoked responses which were classified as 'standard' and 'deviant' and grouped separately. The standard average response which appeared immediately after the deviant stimulus was excluded from the analysis.

The rules used to justify the existence or absence of a response to the passive condition were as follows: CAEP was inspected visually by two raters and considered to be present if an individual CAEP peak (e.g. P1, N1, P2, N2, MMN and P3) had higher amplitude than the pre-stimulus baseline level; and Inspected quantitatively in comparison with the previous findings, and to be considered present if an individual's CAEP components had maximum correlation coefficient (r) and significant value ($P<0.05$). The N1 and N2 components were identified as the most negative peak occurred between 80-150 ms and 180-250 ms, respectively, immediately after the stimulus onset. P1 and P2 were defined as the most positive deflection happened between 55-80 ms and 145-180 ms post-stimulus onset, respectively. P3 was scored between 220-380 ms, illustrated by the most positive peak appeared after the stimulus onset within this response window. The difference of the CAEP waveform for each set of speech stimulus was used to measure the MMN response, which was obtained by subtracting the averaged responses of the deviant stimuli from the averaged responses of the same stimuli presented as the standard. MMN was defined as a component having the largest negativity occurring between 100-250 ms at electrode positions Fz or Cz (Duncan et al. 2009; Li et al. 2016). The appearance of MMN was confirmed when it had more negative amplitudes at the fronto-central electrode site (Fz and Cz) in comparison with the parietal site (Pz). The amplitude of evoked responses was compared with the prestimulus baseline and measured as the greatest amplitude recorded followed by the latency measurements taken at the center of the peak obtained within the respective response window (Duncan et al. 2009; Oates et al. 2002). The late CAEP amplitude and latency components were recorded from each individual response windows to develop the grand-mean-waveforms for each CVs stimulus (i.e. /ba/-/da/ and /ba/-/pa/) respectively as per the two types of experimental groups (i.e. normal hearing (NH) and sensorineural hearing loss (SNHL)). The amplitudes and latencies of various CAEP components were then assessed independently between hearing impaired subjects (SNHL) and controls as 'standard' and 'deviant'.

STATISTICAL ANALYSIS

The independent t-test initially was done on the age between the participants in order to make sure that no other factors might contribute to the main finding of the study. The CAEPs were analyzed using descriptive statistical measurement, correlation coefficient test and the final responses were analyzed using two-way repeated measures analysis of variance (ANOVAs) technique. These statistical analysis tests were conducted using IBM SPSS Statistics 23.0 software. The study involved two stages of correlation coefficient test. Initially, each of individual's responses was compared with the previous study and the standard typical CAEP waveform (Duncan et al. 2009; Näätänen 1992; Sams et al. 1985). Individual response having a maximum positive correlation coefficient (r^2=0.825) with the standard waveform was then selected as the typical standard trend CAEP waveform for the present study. Second stages were done between the rest of the individual subject's responses with the current typical waveform. Individual's responses having maximum correlation and low significant value (P<0.05) were accepted and those having low correlation and high P value (p>0.05) were neglected for further analysis. The CAEPs amplitudes and latencies were then analyzed individually using two-way repeated measures ANOVA to identify the correlation dependence of the CAEPs components on each set of speech stimuli and their relationship between both phonologic features. The two factors highlighted in the ANOVAs were as follows; speech stimuli /ba/-/da/ and speech stimulus /ba/-/pa/. The main effects and interaction with the CAEPs component were considered significant if p<0.05.

RESULTS

Figure 2 demonstrates a sample of individual control group contrast responses towards both sets of speech stimuli. This control subject's response explained the common trends found in the average CAEPs waveform. Typically, as referred to Figure 2, CAEP mean amplitudes exhibit higher activation in the deviant stimulus compared to the standard stimulus for both speech conditions. The CAEP latencies for the placing contrast are substantially shorter and produced lower activation than the voicing contrasts.

Figure 3 shows that there was a trend for both speech stimuli recorded from patient's CAEPs response as well in difference waveforms. Apparently, the deviant stimulus demonstrated higher amplitude and shorter latency compared to the standard type of the placing contrast stimulus. However, voicing contrast stimulus showed the opposite pattern of response. As for the MMN waveform (difference), higher negativity response and longer latency were presented from the feedback towards voicing contrast compared to that of the placing contrast stimulus. Figure 4 shows the average effects of both articulatory features of speech on the amplitudes of the CAEPs waveform, which was recorded at Cz electrode. The results of CAEPs revealed that all average deviant responses produced higher amplitudes activation in accordance with both sets of speech stimulus. However, this evidence was not found in N1 component which corresponded to /ba/-/pa/ stimulus. P1 amplitude of SNHL subjects was larger in response to voicing contrast stimulus compared to that of the control subject. P2 component showed a reverse pattern of response.

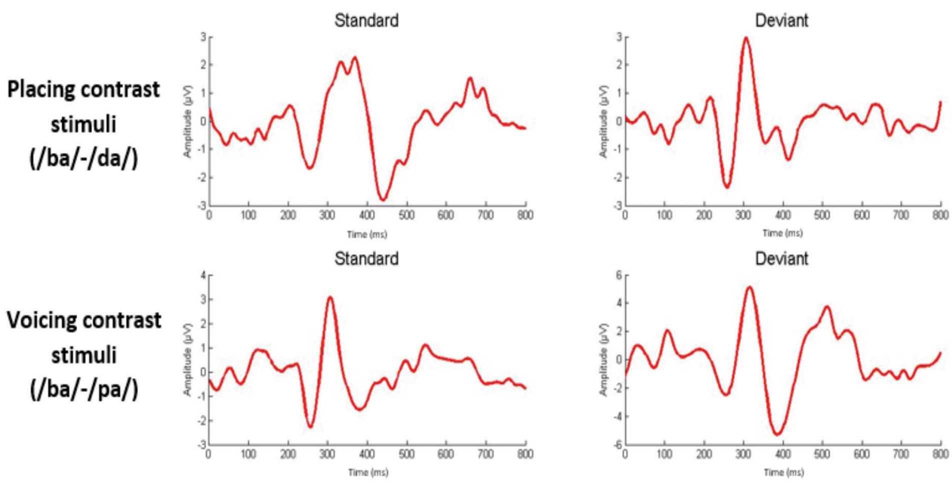

FIGURE 2. Average CAEPs waveforms (Cz) recorded from a control subject. The top row waveforms are CAEP waveforms for the averaged standard and deviant stimulus, which response to the placing contrast stimuli (/ba/-/da/). The bottom row waveforms are CAEP waveforms for the averaged standard and deviant stimulus, which response to the voicing contrast stimuli (/ba/-/pa/)

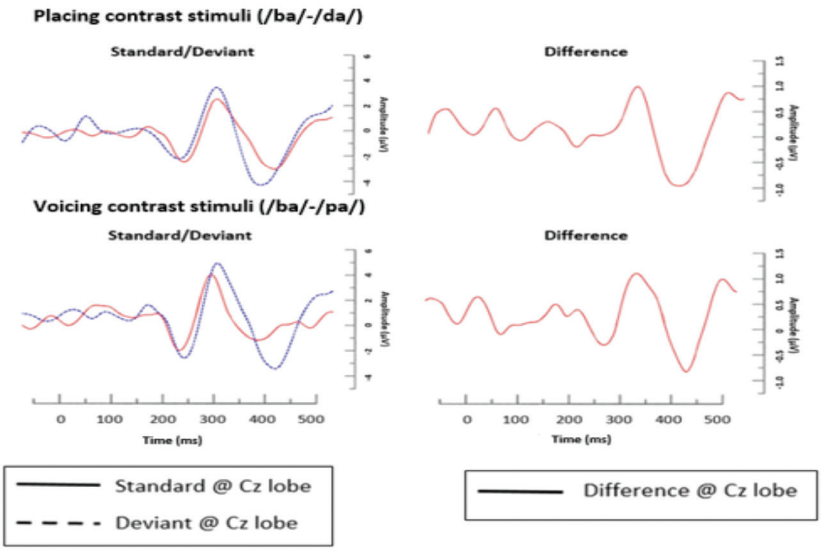

FIGURE 3. Average CAEPs waveforms recoded from a SNHL subject. The top row illustrates the CAEP waveform response to the placing contrast stimuli and the difference waveform recorded at Cz. The bottom row is CAEP waveform response to the voicing contrast stimuli and difference waveform recorded at Cz

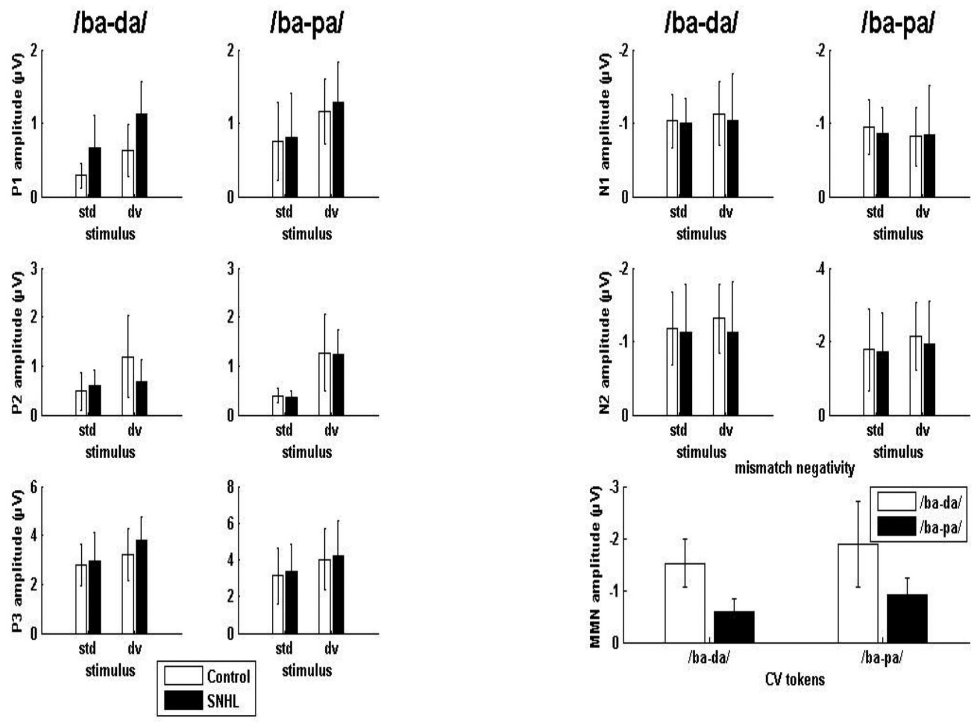

FIGURE 4. Mean and SD amplitude for both control and SNHL groups across two types of speech stimuli

Table 1 shows the amplitudes and latencies of the recorded CAEPs waveform at Cz electrode for both subject groups. P1 component experienced shorter timing response in /ba/-/pa/ stimulus at both groups study. The same response was shown by P2 component in /ba/-/da/ stimulus. Both N1 and N2 components having similarity when both evoked longer average latencies in response to voicing contrast compared to the placing contrast stimulus. Figure 5 shows the individual's data distribution of CAEP P3 components in response to both speech stimuli. SNHL group showed a delayed and greater response towards voicing contrast stimulus. The deviant response on each set of stimuli showed contradictory trend when it showed higher latency and greater amplitude during voicing contrast stimulus but happened at earlier response timing with the same pattern of neuron activation in placing contrast stimulus, and these were true for both SNHL and normal hearing groups.

TABLE 1. Mean and SD latencies of CAEPs components and MMN for control and SNHL groups

	/ba/-/da/ stimuli				/ba/-/pa/ stimuli			
			Control (N=12)	SNHL (N=12)			Control (N=12)	SNHL (N=12)
P1 lat (ms)	Stand	Mean	71.06	74.78	Stand	Mean	68.56	69.65
		SD	9.38	8.12		SD	7.75	5.94
	Dev	Mean	77.50	78.29	Dev	Mean	68.05	70.33
		SD	8.98	5.11		SD	6.52	5.55
N1 lat (ms)	Stand	Mean	108.95	119.28	Stand	Mean	114.40	129.44
		SD	13.32	8.15		SD	10.65	10.61
	Dev	Mean	111.85	126.20	Dev	Mean	122.75	134.50
		SD	10.35	12.10		SD	14.52	6.73
P2 lat (ms)	Stand	Mean	165.75	160.61	Stand	Mean	166.30	170.55
		SD	6.47	6.88		SD	8.11	8.13
	Dev	Mean	164.20	168.06	Dev	Mean	169.90	167.33
		SD	7.71	5.18		SD	10.13	8.16
N2 lat (ms)	Stand	Mean	204.30	232.11	Stand	Mean	220.15	240.65
		SD	19.26	12.77		SD	11.25	15.52
	Dev	Mean	217.85	234.89	Dev	Mean	226.05	240.00
		SD	8.27	10.45		SD	14.29	6.22
P3 lat (ms)	Stand	Mean	315.35	345.00	Stand	Mean	317.00	360.65
		SD	19.52	16.90		SD	12.13	18.57
	Dev	Mean	321.85	348.35	Dev	Mean	324.3	368.95
		SD	17.87	17.48		SD	8.20	21.73
MMN (ms)	Peak lat	Mean	187.30	201.23	Peak lat	Mean	190.91	215.74
		SD	25.76	22.46		SD	23.14	22.06

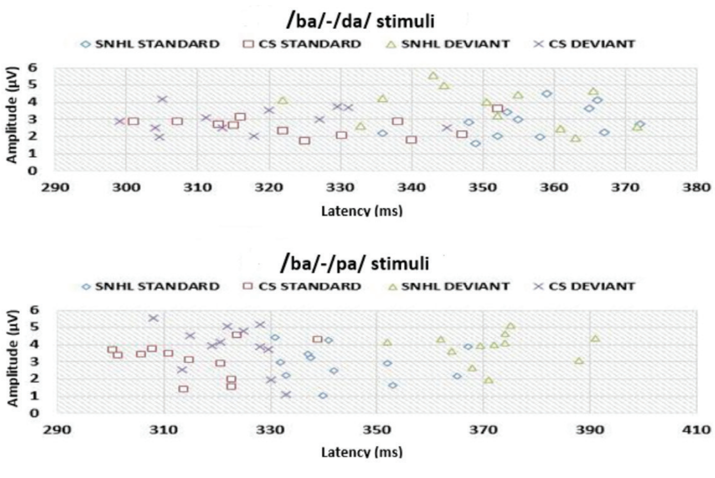

FIGURE 5. Amplitude and latency plots for P3 component for different types of stimuli and subject groups. Scatterplots demonstrate individual amplitude and latency values for P3 component

The result of two-way repeated measures ANOVAs showed that there are no significant differences in the average CAEPs amplitude and latency between the response elicited by the standard and deviant stimuli. Evidence found in both experimental groups with both sets of stimuli; therefore, both types of stimuli were averaged together for that particular articulatory feature to find any significant difference on CAEP components between groups' response to both speech stimuli. The result of the ANOVAs outlined a significant effect for /ba/-/da/ stimuli on P1, N1 and MMN amplitudes. The results of the ANOVAs reported that a significant main effect was found on the P1 amplitude in response to the placing contrast stimulus between groups (p<0.001). No significant difference was found for P1 component in response to voicing contrast stimulus and there was no significant interaction between both sets of speech stimulus (p=0.135 and p=0.406). Both N1 and P3 amplitudes and latencies showed a significant main effect on both speech phonological features between control and SNHL groups (N1: $p<0.001$ vs $p=0.015$, $p=0.006$ vs $p<0.005$; P3: $p<0.001$ vs $p=0.029$, $p<0.001$ vs $p=0.001$). A significant interaction between both types of speech features was found. However, no evidence of any significant interaction was found for N1 amplitude (N1: $p=0.075$, $p=0.038$; P3: $p=0.042$, $p=0.003$). As for MMN response, significant difference was reported in amplitude and latency for their response to /ba/-/da/ stimulus compared to the /ba/-/pa/ stimulus ($p=0.036$ and $p=0.004$). Similarly, no statistical significance was found in the interaction between both sets of speech stimulus.

DISCUSSION

MAIN FINDINGS

The primary purpose of the present study aimed to determine the implication of various speech phonological features towards amplitudes and latencies of late CAEPs components between healthy group and individuals suffering from SNHL on Malaysian Malay native speaker population. The auditory evoked responses were successfully recorded from both study groups. Independent t-test showed that there was no significant difference in age between the control group and the SNHL subjects ($t_{22df}=1.4$, $p>0.05$). In this study, only Central (Cz) electrode was selected for further analysis as it had the most significant effects on CAEP waveforms in response to speech stimuli and it showed the highest signal to noise ratio compared to other electrode sites (Duncan et al. 2009; Korczak & Stapells 2010; Steinhauer 2014). The Cz electrode provided clearer and more stable CAEP waveforms compared to the Fronto-electrode (Fz) on both speech stimuli circumvent in both experimental groups. The presentation of MMN response was maximal in the Cz which was in agreement with the previously reported studies (Duncan et al. 2009; Steinhauer 2014). The percentage of detectability for the CAEP components including both study groups were: P3 was present in 100%, N2 was present in 96.25%, P2 was 76%, N1 was 82.5%, P1 was present in 74.8% and finally MMN which was present in 75% of all averages.

EFFECTS OF THE FEATURES OF SPEECH ARTICULATION ON THE AMPLITUDES AND LATENCIES OF BOTH P1 AND P2

P1 and P2 components both elicited higher mean amplitude in response to voicing contrast compared to the placing contrast stimulus. The result of P1 component reported here fostering similarity with the previous finding where the average amplitude elicited from the SNHL subject was higher than the control group for both stimuli (Schröder et al. 2014). The previous study emphasized the difficulty to assess accurately the P1 component due to the interaction with C1 waves from a visual event-related potential (VERP) component which created a major overlapping mechanism with the P1 CAEP component (Luck 2005). The deviant stimulus of auditory P2 experienced some amplitude increment compared to standard type for both stimuli. This finding complied with that of the earlier study when the researchers outlined the enhancement of the P2 component when targeting infrequent stimulation (Davies et al. 2010; Luck 2005; Steinhauer 2014).

EFFECTS OF THE FEATURES OF SPEECH ARTICULATION ON THE AMPLITUDES AND LATENCIES OF BOTH N1 AND N2

N1 component which originally arising from superior temporal gyrus region provided important aspects in performing spectral and temporal acoustic discrimination tasks during spatial attentional process between various speech articulation features. This is proven when it's having significant main effects on most of the ANOVAs testing (Luck 2005; Näätänen & Picton 1987). We reported that the average mean amplitude of the auditory N1 and N2 were attenuated in SNHL subjects compared to that in normal subjects. This suggested the encoding deficits in auditory processing information of hearing impaired subjects. Our finding agreed with that of the previous studies where the low-level of N1 auditory response was found in subjects with misophonia and aphasia (Becker & Reinvang 2013; Schröder et al. 2014). These similarities suggested that the center auditory process of sensorineural of the subject might interfere with some speech perception disorder. Specifically, the deprivation situation was more prominent in the auditory N1 response towards the place of articulation feature compared to voicing contrast stimulus. In contrast, there were no clear justification involving the resemblance finding between N1 and N2 components, however may indeed reflect the reliance of cortical auditory response towards phonologic features of speech signal (Bien et al. 2016; Carpenter & Shahin 2013; Scharinger et al. 2016).

IMPLICATION OF SPEECH STIMULUS ON MISMATCH NEGATIVITY (MMN) RESPONSE AND P3 COMPONENT

The MMN response was elicited in contrast to Malay CV stimuli due to the presence of the language memory traces. This finding supported the previous decision when MMN response was shown in speech stimuli and were enhance when the individuals having automated access to the native-language phonetic prototypes (Becker & Reinvang 2007; Näätänen 1995). Both normal and SNHL subjects exhibited parallel neurons activation when producing higher negativity response and delayed latencies in voicing contrast stimulus. Our finding showed that the MMN response elicited by the SNHL subjects was smaller (almost half of the activation) and recorded at longer latencies on both CVs speech stimuli compared to that of the control group. In other words, the difference in MMN auditory response of hearing impaired subjects was found to reflect not only the detection of speech phonologic features, but also revealed the anomalies in physiological measure of automatic discriminant ability involving central processing in audition (Näätänen 1995; Näätänen & Escera 2000).

The P3 component increased dramatically when they had 100% appearance for all the average values. The introduction of deviant stimuli resulted in tremendous increment compared to other components; which showed the P3 component as the most influential element in understanding CAEPs waveforms in response to various speech phonologic features as it reflects an involuntary switching of passive listening to the odd or deviant stimulus (Reis & Iório 2007).

In this study, the congruence of majority of the result demonstrated larger CAEP amplitudes and longer latencies for response to the voicing contrast compared to that of the placing contrast across both subject groups. A plausible explanation contributed to this pattern of responses may be related to the spectrum energy correlates within these sets of stimuli. Agung et al. (2006) expressed the domination of low-level spectral energy in speech sound which produced higher N1 and P2 amplitudes with longer latencies happened on P1, N1 and P2 components in comparison with the speech sound having higher frequency spectral energy. One possible explanation coincided with the spectral difference occurred on the frequency separation between formant 1 (F1) and formant 2 (F2) frequencies of voicing contrast having approximately 500-750 Hz which was narrower compared to the placing contrast which having 700-1100 Hz formant separation (Korczak & Stapells 2010; Ting et al. 2011; Wunderlich & Cone-Wesson 2001). This condition likely increased the difficulty to the brain speech discrimination on voicing contrast recognition in comparison with the two consonant contrasts, thus lead to wider activation of cortical neurons resulting in higher voltage and delayed latency recorded during phonemes discriminant task. Tavabi et al. (2009) proved that the deeper part of the brain responded better towards high-frequency stimulation compared to superficial region of the human cortex which responded better to low frequency information, thus indirectly supported the present finding on greater response amplitude. Earlier studies also reported the higher amplitude response on speech stimulus due to the broad frequency spectrum in comparison with that of the tonal stimuli (Wunderlich et al. 2006).

Another possible explanation contributed to this finding was due to the increment in onset voicing duration of the Malay CV /ba/-/pa/ stimulus in comparison to placing contrast stimulus. As shown in Figure 1, the voice onset time (VOT) duration differed between the three syllables. Namely, CV syllables /ba/ and /da/ stimuli had the same configuration of the vocal tract but differ in their VOT, as the release sound for /b/ takes a shorter time than for /d/. During the stimulus presentation involving CV transition, there were no great changes occurred in terms of VOT for /ba/-/da/ stimulus as both exert the same voicing pattern with negative VOT. Conversely, during the CV transition in /ba/-/pa/ stimulus, there was a great alteration in voicing onset duration when the /pa/ syllable having positive VOT (longer), in which voicing for the vowel happened after the plosive burst. These temporal cues properties acted as a major identification of voiced and voiceless phoneme. The rapidly changes of formant transition during CV passage supported the occurrence of higher amplitudes and prolongation timing responses of CAEPs components happened in voicing contrast stimulus, thus underlying passive discrimination process to be a difficult task to operate. Similar study was done by Tremblay et al. (2003) where they highlighted the delayed neuronal synchronous response of the older adult population associated with disruption on the speech discrimination when dealing with time varying speech cues along /ba/ and /pa/ CVs token stimulus. Larger amplitudes and delayed response to stimuli with longer VOT duration were experienced by older subjects.

The current study utilized the CAEP technique in obtaining valuable information using dynamic methods of monitoring the cognitive neurological disorder related to people having sensorineural hearing loss. One of the key advantages of the technique is the sensitivity of CAEP signal in compensating their voltage deflections at higher level processing by specific experimental manipulation especially during selective attention, expectancy, passive listening and memory updating (Duncan et al. 2009; Picton et al. 2000). This indirectly helps the researcher to focus on the stages of processing which are affected by the given experimental manipulation (Luck 2005; Steinhauer 2014). Besides that, the second advantage of CAEP is the capability of this potential activity to be measured online without the need of behavioral response. This greatest advantage makes CAEP recordings possible even without the subject's attention and response. For this reason, the present study assesses various speech CV stimulation to understand how the brain performing CAEP discriminant task between impaired and normal hearing people.

On the other hand, CAEP also has disadvantages especially during the data collection. CAEPs are microvolt level electrical signals that are recorded together with various types of artifact and random noises. Thus, lots of successful trials are needed to maintain the data reliability and accuracy. The successful trials can range from fifty to few thousands per subject for each specific experimental condition (Bidelman 2015; Duncan et al. 2009; Korczak & Stapells 2010; Oates et al. 2002; Wunderlich & Cone-Wesson 2001). This will directly prolong the data recording process and it will be unpractical for certain patient's conditions. In this study, 160 deviant stimuli and 640 standard stimuli were recorded for each subject. This number is in line with requirement of the optimal CAEP recording procedure.

The highly complexity, nonlinearity and non-stationary waveforms characterized by electroencephalogram (EEG) signals make the clinical interpretation a challenging phase. Several non-linear methods presented by previous researchers including sample entropy (SampEnt), higher order spectra (HOS), fractal dimension (FD) and recurrent quantification analysis (RQA) provide a better and valuable mechanism for result interpretation (Acharya et al. 2015, 2011; Chua et al. 2011, 2009). For the last two decades, more exploration was conducted using nonlinear dynamic method in giving potential understanding as this technique extracts hidden complexity in the time series brain signal (Lehnertz 2008; Mormann et al. 2005, 2003). According to Acharya et al. (2013), higher order spectra (HOS) method is considered as one of powerful mechanisms to justify the presence of abnormalities, besides usefulness in the event of signal distortion due to Gaussian noise. This framework has been persistently used in the field to study epilepsy disorder (Chua et al. 2011, 2009).

In earlier studies, Babloyantz et al. (1985) used non-linear methods such as correlation dimension (CD) and largest Lyapunov exponents (LLE) to study the human brain signal during the sleep cycle. Besides that, Song et al. (2004) used recurrence quantification analysis (RQA) method to scrutinize cortical functional at different sleep stages including people suffering from sleep apnea syndrome.

In 2012, a group of researchers took the initiative to propose a method using four different entropies, i.e. approximate entropy, sample entropy, phase entropy 1, and phase entropy 2, to interpret EEG signals involving epilepsy disorder. With the application of various classifiers, fuzzy classifier was concluded as the best technique and the most suitable tool in performing automatic detection of normal, pre-ictal and ictal conditions of epilepsy with an accuracy of 98.1% (Acharya et al. 2012).

Extended idea was done by the similar author Acharya et al. (2015) using several non-linear methods on EEG signal analysis for developing robust automated diagnostic system for depression called depression diagnosis index (DDI). The authors also implemented several types of classifier, which finally conclude that support vector machine (SVM) as the most effective classifier in terms of accuracy, sensitivity and specificity. The novel features combination in the study proved the efficacy of non-linearity method in assisting medical professionals by developing diagnostic index tools for measuring the severity of depression (Acharya et al. 2015).

To improve signal denoising process, Wang et al. (2013) proposed a method called empirical mode decomposition (EMD). The adaptation of this method was widely used in short inter-stimulus intervals, i.e. when inverse process of overlapping between desired CAEPs may occur. The authors had successfully improved the signal-to-noise (SNR) ratio in the raw EEG signals in order to optimize the nonstationary signals.

The current study used the conventional approach in measuring CAEPs components by averaging typically hundreds of electroencephalogram (EEG) signals at low stimulus rate so that random noises and various other types of artifact were removed. This commonly used technique was in line with our present experimental paradigm since we are using 250 ms stimulus duration with long inter-stimulus intervals (800±200 ms). To resolve the issue of deconvolution (inverse filtering), the standard stimulus which emerged immediately after the deviant stimulus, were excluded from the data analysis (Korczak & Stapells 2010; Wang et al. 2013).

Conclusion

Our study done on local ethnic Malay population, had proven the significant effects of cortical auditory evoked potential (CAEP), in discriminating speech acoustical complexity with various speech phonological features in people with sensorineural hearing loss. CAEP signals appeared to be an effective way to study the auditory processing stages and ailments related to the brain. The mean CAEP amplitudes and latencies for most of the CAEP components were considerably larger and delayed in response to voicing contrast compared to placing contrast. MMN was clearly elicited in both study groups which showed that the MMN is a suitable tool in performing behavioral change detection as well as in the attention-dependent physiological measures of the human auditory pathway. It may be easier for brain to discriminate the cues of the placing contrast compared to that of the voicing contrast through shorter response time and lower amplitude. This result is likely due to the larger frequency spectral and longer time varying that present between these speech contrasts. The present finding would be of great help to clinicians in selecting appropriate features of speech articulation that can give good response in evaluating passive speech perception among people with sensorineural hearing loss. In light of this development the research also conveys better knowledge regarding brain mechanisms in discriminating various speech phonemes. The outcome of presence study might be helpful for clinical diagnosis, to help further in investigate the effects of central auditory processing in elderly people with sensorineural hearing impairment.

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