EFFECT OF AUDITORY AND VISUAL DISTRACTERS ON BRAINSTEM ENCODING OF SPEECH

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Abstract

The present study was taken up to measure the effect of auditory and visual distracters on the brainstem encoding of speech. Speech evoked auditory brainstem responses were recorded in fifteen normal hearing adults for synthetically generated /da/ presented to the right ear in four experimental conditions- Baseline, with meaningful auditory distracter stimulus, with non-meaningful auditory distracter stimulus and with visual distracter stimulus. The transient response obtained was visually analyzed to note down the latency and amplitude of wave V and A. whereas frequency following response was subjected to FFT to derive the magnitude of response at F0, H2 and H3 and H4. The results revealed that there is no main effect of condition on the latencies and amplitudes of wave V and A. However, the spectral magnitude of the third harmonic centred around 343Hz reduces in the test ear when a meaningful distracter is presented in the auditory modality. Such an influence was not present with non-meaningful auditory distracter or the visual distracter. Based on the findings of the present study it can be inferred that the semantic load of the distracter stimuli has a significant influence on the activation of the corticofugal regulation and in turn on the brainstem encoding of speech.

Key words: *Speech ABR, attention, distracter, brainstem encoding*

Introduction

Auditory stimulus, on its way from the peripheral level to the cortical level passes through a spectrum of structures and sensory encoding at each of this level is a determining factor for accurate sound perception. Although non speech stimuli such as clicks and tone bursts are usually used to check the neural synchrony of the auditory brainstem, our brainstem is also capable of encoding the complex stimulus such as speech. The transmission and the coding of the speech stimulus are known to be more complex (Johnson, Nicol, & Kraus, 2005).

Selective attention is the ability to respond in a predetermined manner to only one or a small subset from a number of equally potent stimuli. It helps in focusing attention on a sound of interest amidst irrelevant signals and is vital for survival (Bharadwaj, Lee, & Shinn-Cunningham, 2014). With respect to auditory selective attention, one of the most primary research questions has been whether selective attention modulates sound processing at the cortical level, or whether attention induced modulations takes place at the level of sub-cortical auditory structures and cochlear structures also. Results from the physiological studies reveals that selective attention (attending to one stimuli while ignoring another stimuli) modulates the functioning of the cochlear outer hair cells, thereby facilitating the processing of the target stimuli (Bidet-Caulet et al., 2007; de Boer & Thornton, 2007; Meric & Collet, 1992). But the generality of this finding has been questioned by researchers (Michie, LePage, Solowij, Haller, & Terry, 1996). Over the past four decades researchers have explored the effect of attention on cortical event related potentials (ERPs). Hillyard and colleagues dichotically presented 2 similar series of tone pips and required participants to attend only to tones played to the designated ear (Hillyard, Hink, Schwent, & Picton, 1973). Comparison of the ERP responses to the same tones when attended and unattended revealed an enhanced N1 component to attended tones. Selective attention is also found to affect steady-state responses in the primary auditory cortex, and transient and sustained evoked responses in secondary auditory areas (Bidet-Caulet et al., 2007). The magnitude of the cortical exogenous and endogenous auditory evoked potential (Choi, Rajaram, Varghese, & Shinn-Cunningham, 2013; Hackley, Woldorff, & Hillyard, 1990) as well as ASSR (Wittekindt, Kaiser, & Abel, 2014) have been observed to increase when subjects are actively listening for an auditory stimulus compared to when they perform a visual task or are ignoring the same auditory inputs. Kadobayashi and Toyoshima reported no significant effect on latency but significant reduction in amplitude of the early portions of middle latency potentials (MLPs) to binaural 50 dB SL clicks during attention (Kadobayashi & Toyoshima, 1984).

On critically evaluating the literature, one can understand that attention facilitates signal processing and in the absence of actual attention, processing is poor. This is particularly true with cortical auditory potentials. However research on the effect of attention on subcortical structures is few. Gregory, Heath and Rosenberg compared click evoked BAEPs elicited during visual attention and during auditory attention but could find any effect attributable to changes in states of attention (Gregory, Heath, & Rosenberg, 1989). Similar results have been reported by Gutschalk, Micheyl and Oxenham (2008). However there is ample of anatomical evidence for the existence of corticofugal connections to the sub-cortical structures including the brainstem

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(Ades et al., 1974; Müller, Schlee, Hartmann, Lorenz, & Weisz, 2009; Winer, 2006). In animals, efferent projections from auditory cortex play a role in the long-term plasticity of the neural firing properties of a number of different sub cortical structures, including outer hair cells (Suga, Xiao, Ma, & Ji, 2002), cochlear nucleus, superior olivery complex (Saldaña, Feliciano, & Mugnaini, 1996), neurons in inferior colliculus (Bajo, Nodal, Moore, & King, 2010; Yan & Suga, 1996), and possibly at later sub-cortical processing stages as well. In humans, Lucas and Brix investigated the effect of attention on click evoked auditory brainstem responses and reported a decrease in the inter-peak latency time (Lukas, 1980). Several studies by Galbraith and colleagues reported that the amplitudes of ASSRs are modulated by both inter-modal attention (Gary C Galbraith, Olfman, & Huffman, 2003) and selective auditory attention (Galbraith & Arroyo, 1993; G C Galbraith, Bhuta, Choate, Kitahara, & Mullen, 1998; G C Galbraith & Doan, 1995). More recently, Hairston, Letowshi and McDowell found that the ASSR amplitude to task-irrelevant tones decreased during an auditory task, but did not change during a visual task, potentially indicating a subcortical suppression of irrelevant stimuli in challenging listening situations (Hairston, Letowski, & McDowell, 2013). Selective attention is also known to influence envelope following response (EFR) (Lehmann & Schönwiesner, 2014).

As reported by Chandrasekaran and Kraus and Chandrasekaran, Skoe and Kraus there is evidence for existence of continuous, online modulation of brainstem encoding by the auditory cortex via corticofugal pathways in humans and they termed it as online plasticity (Chandrasekaran & Kraus, 2010; Chandrasekaran, Krishnan, & Gandour, 2009; Skoe, Chandrasekaran, Spitzer, Wong, & Kraus, 2014). This online plasticity is known to regulate the way brainstem encodes speech based on the stimulus statistics, thereby suggesting that the brainstem encoding of speech is not a passive functioning as understood with click evoked ABRs. Functionally, the online modulatory mechanism is found to regulate speech perception in noise (Musacchia, Strait, & Kraus, 2008). Considering that the brainstem processing is not a passive process, one could expect that a competing signal delivered to the opposite ear will influence the brainstem encoding of speech. In the presence of a distracting stimulus, the influence of corticofugal pathway may vary and thereby leading to differences in the speech ABR. In such a case, one would also be curious to attempt to understand whether a distracter in the auditory domain versus a distracter in the visual domain would have the same influence. However, till date there are no studies that have probed into the effects of distracting stimulus on the brainstem encoding of speech. The findings of such a study would throw light on the mechanisms of corticofugal modulation and brainstem encoding. Therefore the present study was taken up to test the effect of auditory and visual distracters on onset and sustained brainstem responses elicited by /da/. It was also of interest to compare the effect of meaningful and non-meaningful auditory distracters on onset and sustained brainstem responses elicited by /da/.

Method

Participants

Fifteen adults (7 females and 8 males) in the age range of 18 to 24 years, with normal or corrected-to-normal vision participated in the study. All participants were native speakers of Kannada who had learnt English as their second language and proficient in using numeric keypad. Prior to the speech ABR measurements, all participants had to undergo pure tone audiometry, tympanometry, and oto-acoustic evaluation to rule out the involvement of any abnormality (Structural or functional abnormality-hearing loss, middle ear pathology).

In pure-tone audiometry, hearing thresholds of less than 15 dB HL in both ears at frequencies (0.5, 1.0, 2.0, 4.0, & 8.0 kHz) was the qualifying criteria. Type A tympanogram (determined using Jerger's [1970] classification system) and presence of acoustic reflexes in both ears ensured normal middle ear functioning. Screening Checklist for Auditory Processing in Adults (SCAP-A) developed by Vaidyanath and Yathiraj was administered to screen for Central Auditory processing disorders (Vaidyanath & Yathiraj, 2013). Only participants with score of less than 50% (a score <= 6) were considered for the present study. Click evoked ABR was recorded prior to the speech ABR recording to check the integrity of neural pathway at the levels of brainstem. Only if the results of click ABR were normal, the individuals were considered as participants of the study.

All the participants were blindfolded to the purpose and objectivity of the study. An informed written consent was taken from each participant, prior to their inclusion, after explaining them the details of test procedure and the purpose of the study.

Instrumentation

All the audiological tests were administered in a sound treated audiometric room where noise levels were within permissible limits (ANSI S-3, 1991). A calibrated two channel diagnostic audiometer, GSI-61 (Grason-Stadler Incorporation, USA) with Telephonics TDH 39 supra aural headphones and Radio ear B-71 bone vibrator calibrated as per ANSI (2004) was used for puretone audiometry. GSI Tympstar (Grason-Stadler Incorporation, USA) clinical immittance meter, calibrated as per ANSI (1987) was used for immittance evaluation. DPOAEs were recorded using a laptop computer with ILOv6 (ILO= Institute of Laryngology and Otology; version 6) software. ILO 292 DP Echo port system (Otodynamics Inc., UK) was used to assess transient evoked oto-acoustic emissions. Adobe Audition 2.0 (Adobe Systems Inc) installed on a Dell Inspiron 15 3000 series laptop (Realtek sound card) with AHUJA AUD- 101XLR dynamic unidirectional microphone was used for recording the distracter stimulus. A Biologic Navigator Pro EP (Natus Medical Inc., Mundelein, USA) system was used to record auditory brainstem responses. A numeric keypad was be used for the participants to register their task specific responses.

Test stimulus

Two types of stimuli were used for the experiment; stimulus for eliciting ABR and distracter stimuli. Speech Evoked ABR was recorded for a synthetically generated syallable /da/. Five-formant synthesized /da/ was 40 milliseconds in duration and is provided with the BioMARK module in Biologic Navigator Pro. The stimulus was constructed to include an onset burst frication at F3, F4, and F5 during the first 10 ms, followed by 30 ms F1 and F2 transitions ceasing immediately before the steady-state portion of the vowel. The stimulus did not contain a steady-state portion.

Distracter stimulus on the other hand was presented either in the auditory or visual modality only. For distraction in the auditory modality both meaningful and non meaningful distracter stimulus was used.

For meaningful auditory distracter stimulus (MAD stimulus), 120 English words were selected from 4 lexical categories (vehicles, animals, common objects and birds) i.e. 30 words from each lexical category. The selected words were recorded using Adobe Audition 2.0 (Adobe Systems Inc) at a sampling rate of 44,100Hz. These words were initially played to 5 listeners to evaluate whether they can be readily associated with the lexical category they belong to. During the experiment a set of 4 words (3 from one lexical category and 1 from another) was played to the participants and a 'pick the odd one out' task was given.

Non-meaningful auditory distracter stimuli (NMAD stimulus) were time reversed version of the MAD stimulus. In the time reversed version the same 120 words were played in reverse, this was done using Adobe Audition 2.0. This stimulus had same spectral and temporal characteristics as in MAD stimulus but was non-meaningful. During the experiment a set of 4 NMAD stimuli (3 time reversed same word and 1 time reversed different word) was played to the participants and a 'pick the odd one out' task was given.

The visual distracter (VD) stimulus constituted of pictures representing the 120 selected words. During the experiment a set of 4 stimuli (3 from one lexical category and 1 from another) was displayed on the laptop screen against a white background and a 'pick the odd one out' task was given.

Procedure

The electrophysiological responses were recorded in an electrically shielded, sound treated room. The participants were comfortably seated on a reclining chair, instructed to relax the body and refrain from unnecessary body movements to avoid artefacts. Stimulus and recording parameters for recording speechABR followed BioMARK protocol (Bio-logic, 2005). The 100 µs click stimulus was presented to the right ear with rarefaction polarity at 80 dBnHL via ER-3A insert ear phone, at a repetition rate of 30.1/s. Two sets of 1500 artifact-free sweeps were collected for the click and two sets of 3000 artifact-free sweeps were collected for the /da/ stimulus for each condition. Responses were collected with silver chloride electrode, differentially recorded from Cz (active) to ipsilateral mastoid (reference), with the opposite ear mastoid as ground. The responses to /da/ stimulus were sampled at 12 kHz; bandpass filtered from 100 to 2000 Hz, and averaged using a analysis window of 70ms.

The distracter stimulus was presented in a four interval forced choice method using Paradigm Stimulus Presentation Software (Perception Research Systems, 2007) installed on a Dell Inspiron 15 laptop with the output routed through a calibrated audiometer and distracter stimuli presented to the left ear through an ER3A (Etymtotic Research. Inc) insert earphones connected to the audiometer at an overall intensity of 40dB SL. To register participant responses a numeric keypad with each number assigned to a target lexical category was used. Prior to commencing of the experiment, participants were briefed regarding the task.

The speech ABRs were recorded under four experimental conditions; Baseline (BL), with meaningful auditory distracter, with non-meaningful auditory distracter and with visual distracter. Baseline recording was done in the absence of visual or auditory distracter. The MAD and NMAD stimuli were presented in the left ear and the participant was instructed to pay attention to the stimulus set that is being played, and was required to identify the position of the odd stimuli within the set by pressing the corresponding key on the keypad (1, 2, 3 or 4). A minimum score of 80% was required in the identification task to ensure that the participant has attended to the distracter. The VD was displayed on a laptop screen without audio playback. The participants were required to identify odd stimuli from the set of by pressing the corresponding key on the keypad (1, 2, 3 or 4). The position of the odd stimulus across trials, stimuli set across trials and the order of the experimental conditions were randomized.

Analysis

The recorded Speech ABR waveforms were analysed for transient and the sustained portion (Frequency following Response) by the experimenter to identify wave V and A. Sustained portion of the response was be analyzed using FFT. Data was converted to a text file and imported to the Brainstem Toolbox (Skoe & Kraus, 2010) using MATLAB vR2009b. The data was then subjected to spectral analysis after zero padded windowing (10 to 60 ms with 5 ms taper Hanning window) of the FFR waveform. The spectral magnitude in ten 1Hz bins around the centre frequencies of 114 Hz, 228 Hz, 343 Hz and 456 Hz were averaged to obtain the spectral magnitudes corresponding to the fundamental (F0) and the second through 4th harmonics (H2, H3 and H4).

Results

Results of Onset responses

The onset peaks V and A were marked and their latencies and amplitudes were noted down. Mean and standard deviation of the peak latency of wave V and A in the four experimental conditions are given in Table 1. Comparison of the man data across the four conditions showed that there were marginal differences across the four conditions in wave V as well as A. The mean latencies were statistically compared across the four conditions using Friedman non parametric test. The results revealed that there is no main effect of condition on the latencies of V [Friedman test statistic = 5.965, df = 3, $p > 0.05$] and A [Friedman test statistic = 1.017, df = 3, $p > 0.05$].

Table 1: Mean and standard deviation (in parenthesis) of the peak latencies of wave V and A in the four experimental conditions

Measure	Experimental conditions	Mean (ms)
Wave V latency	BL	6.349 (0.21)
	MAD	6.361 (018)
	NMAD	6.404 (0.20)
	VD	6.305 (0.19)
Wave A latency	BL	7.295 (0.60)
	MAD	7.396 (0.35)
	NMAD	7.339 (0.26)
	VD	7.391 (0.29)

Table 2 shows the mean and standard deviation of the peak amplitudes of wave V and A in the four experimental conditions. Similar to latencies mean peak amplitudes also varied marginally across four conditions and results of Friedman test showed no significant main effect of condition on the amplitude of both wave V [Friedman test statistic = 5.082, df= 3, $p > 0.05$] and A [Friedman test statistic = 2.434, df = 3, $p > 0.05$].

Table 2: Mean and standard deviation (in parenthesis) of the peak amplitudes of wave V and A in the four experimental conditions

Measure	Experimental conditions	Mean (µV)
Wave V amplitude	BL	0.159 (0.07)
	MAD	0.140 (0.08)
	NMAD	0.161 (0.06)
	VD	0.159 (0.04)
Wave A amplitude	BL	-0.299 (0.10)
	MAD	-0.273 (0.07)
	NMAD	-0.271 (0.08)
	VD	-0.285 (0.07)

Results of Frequency following responses

The spectral magnitudes at F0 and the three subsequent harmonics were noted from each averaged waveform. Mean and standard deviation of the spectral magnitudes of the four harmonics (F0, H2, H3 and H4) in the four experimental conditions are given in Table 3. The observation of mean data shows that the spectral magnitude was higher in baseline and visual distracter conditions compared to the two auditory distracter conditions. This is true with all the four harmonics. Results of Friedman test showed a significant main effect of condition on the spectral magnitude at H3 [Friedman test Statistic = 7.971, df = 3, $p < 0.05$], while there was no significant effect on spectral magnitudes of F0 [Friedman test Statistic = 2.057, df = 3, $p > 0.05$], H2 [Friedman test Statistic = 2.657, df = 3, $p > 0.05$] and H4 [Friedman test Statistic = 0.600, df = 3, $p > 0.05$].

Table 3: Mean and standard deviation (in parenthesis) of the spectral magnitudes of the four harmonics (F0, H2, H3 and H4) in the four experimental conditions

Measure	Experimental Conditions	Mean Amplitude (µV)
F0	BL	0.083 (0.08)
	MAD	0.065 (0.03)
	NMAD	0.058 (0.04)
	VD	0.075 (0.03)
H2	BL	0.028 (0.01)
	MAD	0.021 (0.01)
	NMAD	0.024 (0.01)
	VD	0.025 (0.01)
H3	BL	0.015 (0.00)
	MAD	0.012 (0.00)
	NMAD	0.011 (0.01)
	VD	0.017 (0.01)
H4	BL	0.011 (0.006)
	MAD	0.010 (0.006)
	NMAD	0.010 (0.005)
	VD	0.013 (0.007)

Because there was a main effect of condition on the spectral magnitude at H3, it was further subjected to Friedman's pair wise comparison to check which of the conditions were statistically different. The results showed that spectral magnitudes at H3 were significantly different between the baseline and MAD condition [Friedman test statistic = 2.664, df = 3, $p < 0.05$], MAD and VD condition [Friedman test statistic = 2.194, df = 3, $p < 0.05$]. The same however was not true for the baseline and NMAD [Friedman test statistic = 1.881, df = 3, $p > 0.05$], baseline and VD [Friedman test statistic = 0.470, df = 3, $p > 0.05$], MAD and NMAD [Friedman test statistic = 0.784, df = 3, $p > 0.05$], NMAD and VD [Friedman test statistic = 1.410, df = 3, $p > 0.05$] conditions.

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Discussion

The purpose of the present study was to investigate whether auditory and visual distracters affects onset and sustained brainstem responses elicited by /da/. It was also of interest in the present study to compare the effect of meaningful and non-meaningful auditory distracters on the same. The results of the present study revealed a significant influence of meaningful auditory distracter on the sustained brainstem response. However no such influence was present on the onset responses.

In the present study the distracter was presented to the left ear while recording Speech ABR from the right ear. The decrease in the FFRs in the presence of distracter indicates that the distracter stimulus in the opposite ear affects the temporal precision of the brainstem encoding of speech. Although the exact mechanism through which the stimulus in the opposite ear interferes with the brainstem encoding is not clear, the deviated attention could be playing a significant role.

Compared to the baseline wherein no task is assigned, the brainstem encoding of the sustained portion was observed to be inhibited on the addition of a sensory driven task in the auditory domain. Specifically, the responses decreased when the distracter presented was meaningful. This may be explained considering that the brainstem does not code meaning of a stimulus; hence the difference in the influence of distracters suggests the involvement of cortical structures in the brainstem encoding. In the presence of a meaningful distracter, the process of fine tuning of brainstem encoding through corticofugal pathway seems to be suppressed. However, whether such decrease in the fine tuning is due to interference in the stimulus probability judgements by the cortex or due to an unknown disturbance in the corticofugal regulation is a topic of debate. The finding that only meaningful distracters influenced the brainstem responses can be used as a support for attention playing the role in the process of distraction.

Another important finding of the present study was that the reduction in spectral amplitude is not present for task in the visual domain. This suggests that the modulation of the brainstem responses is present only when the distracter stimulus is within the same modality. This would mean that the mechanisms of distractions are different across the different modalities. The distracter in the auditory domain imposes greater challenge for brainstem encoding. Considering that the brainstem does not code meaning of a stimulus, difference in the influence of meaningful and non-meaningful distracters suggests the involvement of cortical structures in the brainstem encoding. One can draw conjecture that probably the higher cortical structures that code the meaning of the stimulus modulate the brainstem encoding through corticofugal pathway.

The striking fact that the spectral magnitude of only the third harmonic centred around 343 Hz other harmonics were affected highlights the specificity of the cortico-fugal suppression. The results of the present study are in line with earlier reports by Hairston, Letwoski and McDowell who probed into the effect of auditory and visual attention on FFR elicited by pure tone stimulus and reported a reduction in spectral magnitude of harmonic centred at 220 Hz (Hairston et al., 2013).

Overall, results of the present study are suggestive of a top-down (corticofugal) phenomenon which is responsible for the spectral magnitude inhibition. Though the present study cannot pinpoint to the neurophysiological source of the observed inhibition, the results can be better explained taking into consideration earlier reports of existence of a descending trisynaptic link between auditory cortex and peripheral auditory structures via inferior colliculus (Saldaña et al., 1996; Winer, 2006). Hence it is safe to conclude that brainstem encoding of speech is not a passive functioning as understood with click evoked ABRs. There exists a continuous, online modulation of brainstem encoding by the auditory cortex via corticofugal pathways. Another striking fact is that semantic content of the distracter stimuli has an influence on the activation of the corticofugal regulation and in turn on the brainstem encoding of speech.

Conclusions

Based on the findings of the present study it can be inferred that the brainstem encoding of speech is an active process and is continuously modulated via the corticofugal pathways. This online modulation is specific and is more for competing stimuli in the same sensory domain. Furthermore, the semantic load of the distracter stimuli has a significant influence on the activation of the corticofugal regulation and in turn on the brainstem encoding of speech.

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