

# BANGALORE SPEECH AND HEARING TRUST

# Journal of Hearing Language and Speech

ENGLISH HALF YEARLY

VOLUME I | ISSUE 2 | KARENG/2022/83838-BENGALURU | January-June 2023 | PRICE: Rs. 700/-

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## Information about the journal

The JHLS is a biannual publication of the Bangalore Speech and Hearing Trust.

### Aims and Scope

JHLS publishes papers in both clinical and basic research related to hearing, balance, speech – language and swallowing. Articles accepted will be research articles, case studies, tutorials, perspective articles, policy and practice briefs and resource reviews. The articles selected will be peer reviewed. All articles are protected by copyright. Although care is taken in selection of articles, no legal responsibility for errors of omission will be accepted by either the author, editors, or publisher. No warranty is made for the content in the journal.

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# Editorial

Publish or perish is the current mantra. Many Universities or teaching institutes recognise and incentivise publications only if the publications are in indexed or high-impact journals. Hence, the concern in starting new journals is whether they serve a niche need. The process of starting and sustaining a journal is a huge endeavour involving the support of all researchers. I am grateful to the authors and reviewers, who gave up their time to support a new journal.

I am happy that we have some exciting fare to offer in the second issue of the first volume. Dr Ananthanarayan Krishnan has shared his vast experience on the cortical pitch through an article on the “Cortical Pitch Response”, which is a complete treatise on stimuli and methods to measure a pitch-specific response as well as the effect of experience, the interplay of the brainstem and cortical components of responses to pitch *and* the role of the right hemisphere in processing linguistic and non-linguistic aspects of pitch. The Pitch Onset Response on MEG and the Cortical Pitch Response (EEG) to pitch acceleration, height and contour, contour direction and influence of pitch salience and language experience are discussed. The review and insightful analysis will be of interest to researchers as well as students of psychophysics. This resource will induce many to plan research in this area.

The case study on ARSACS syndrome is complete and in thorough detail. Clinical case studies are an important part of journals and of interest to all.

Finally, the resource review, this time on Dr. Brooke Hallowell's second edition titled Aphasia and other acquired language disorders: A guide to excellence.

At the end of the first year of publication, I would like to place on record my thanks to all the editors in the panel for their unstinting support as well as the support of my colleagues in the work associated with bringing out a journal.

Happy reading.

**Madhuri Gore**  
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**of Speech & Hearing**

# Cortical Pitch Response: Characteristics and differential sensitivity to temporal attributes of dynamic pitch stimuli

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## Abstract

Pitch, a robust perceptual attribute, plays a critical role in processing information relevant to speech, language, and music. Thus, pitch offers an effective analytic window to advance our understanding of how tonal language experience shapes processing of linguistic pitch at subcortical and cortical levels in a well-coordinated pitch processing network. The review here focuses on the sensitivity and temporal dimensions of language experience dependent shaping of linguistically relevant pitch processing as reflected in the simultaneously recorded pitch specific measures at the cortical level (cortical pitch response: CPR), and its interplay with the brainstem frequency following response (FFR). We provide strong evidence that the components of the CPR and the FFR are differentially sensitive to the perceptually relevant temporal parameters (temporal regularity (relevant to pitch salience), pitch acceleration, pitch height, and variations in pitch contour) of dynamic pitch stimuli. For example, we have shown that the Na-Pb component of CPR is sensitive to pitch, its salience and height. Pb-Nb, in contrast is sensitive to pitch acceleration. The CPR components may also index both experience-dependent extrasensory and experience-independent sensory effects. Direct comparisons of the effects of parametric variation of several temporal attributes of pitch on the response amplitude at the brainstem and cortical levels revealed different patterns for the cortical and brainstem responses in the Chinese group. This finding is consistent with an experience-dependent transformation in pitch processing from the brainstem to cortical levels, likely mediated by sensory and/or top-down extrasensory processes with bottom-up input from the brainstem. Finally, our findings converge with extant literature that attests to the crucial role of the Right Hemisphere in the processing of linguistic as well as nonlinguistic pitch. Further experiments, that parametrically manipulate temporal attributes of pitch, are needed to advance our understanding of the organization and interplay between the subcortical and cortical components of experience shaped pitch processing network. The results of these experiments would be essential to development of a framework to understand both nature of the interplay between levels of processing and interactions between sensory and cognitive processes influencing pitch representations.

**Keywords:** Cortical Pitch Response; Frequency following response, Pitch Salience, Pitch acceleration, Pitch Height, Pitch contour, Hemispheric Asymmetry.

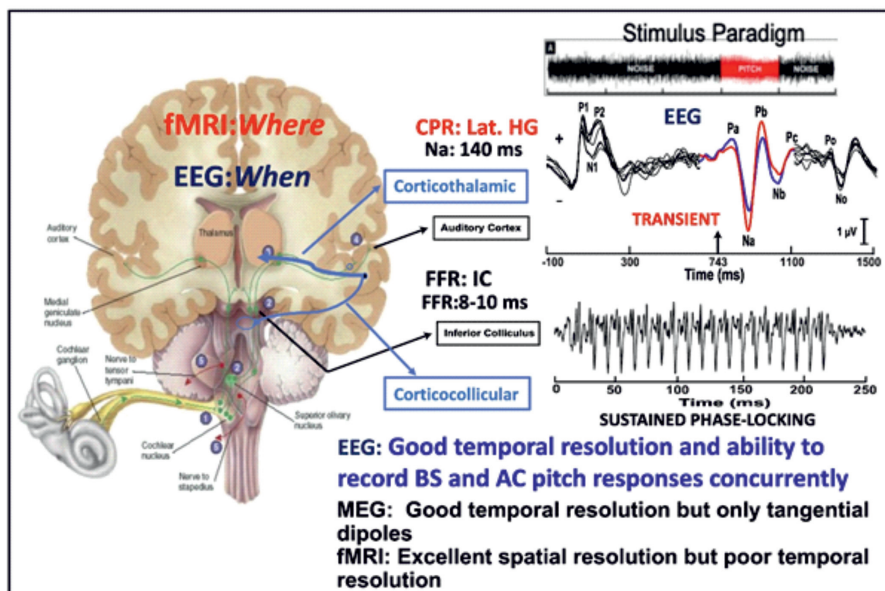
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## Introduction

Pitch, a robust perceptual attribute that is crucial in speech, language, and music processing. Thus, it provides an effective analytic window to study the influence of tonal language experience on the processing of linguistically relevant pitch in both cortical and subcortical structures of a well-coordinated, hierarchical network. Our view is that a complete understanding of the neural organization of language (and music) requires the assumption that linguistic (musical) computations are implemented in the brain in real-time at different stages of hierarchical processing (Embick & Poeppel, 2006). For pitch, complex stimuli bearing pitch information are transformed into neural representations at different stages of processing modulated by experience-dependent sensitivity to relevant temporal attributes.

There are several experimental approaches to evaluate processing of pitch relevant information along different levels of the processing hierarchy. Two approaches that provide excellent temporal resolution (enables study of the temporal evolution

of processing in the millisecond range- *When?*) but limited spatial resolution (*Where?*) are the evoked potentials extracted from scalp sensors using Magnetoencephalography (MEG), and from scalp electrodes using electroencephalography (EEG). EEG records the electrical activity relevant to neural processing, and MEG records the magnetic fields created by the electrical activity relevant to neural processing (figure 1). MEG is relatively more sensitive and precise since it is not susceptible to the skull and cerebrospinal fluid (CSF) induced distortions associated with EEG recordings. However, MEG activity is largely limited to dipole sources that are oriented tangentially. fMRI (functional Magnetic Resonance Imaging) is another approach that evaluates subtle regional blood flow changes in the brain presumably associated with neural processing. Unlike EEG and MEG, fMRI provides high spatial resolution (*Where?*) but has a poor temporal resolution. Increasingly, both approaches are being integrated to measure occurrence of stimulus related neural activity - address questions of both temporal (*When?*) and spatial resolution (*Where?*).



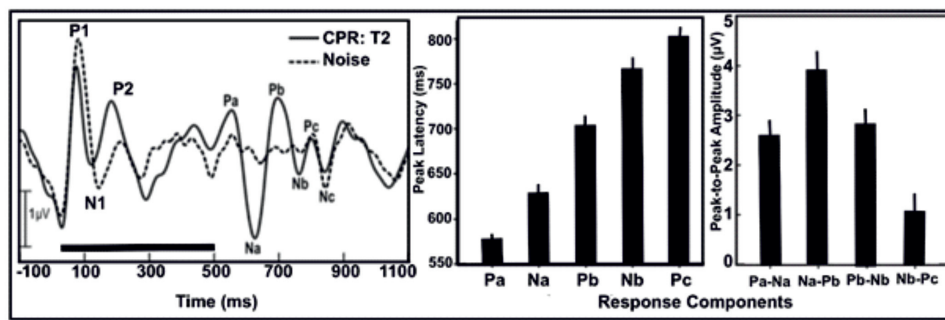
**Figure 1.** EEG and fMRI experimental strategies for pitch evaluation at the cortical and brainstem levels. Shown on the left are the auditory pathways identifying the inferior colliculus (IC) Heschl's gyrus (HG)-presumed generator sites for the FFR and the CPR, respectively. Corticofugal pathways are also identified. The novel paradigm to concurrently record EEG derived CPR and FFR are shown on the right. EEG measures have high temporal resolution but poor spatial resolution. fMRI measures are complementary in that they have high spatial resolution but poor temporal resolution. Integration of the two provides a powerful approach to study the spatiotemporal organization of the pitch processing network.

Recent empirical data using EEG and/or MEG have shown that neural representation of pitch is shaped by one's experience with language and music at the level of the auditory brainstem as well as the cerebral cortex (Besson, Chobert, & Marie, 2011; Gandour & Krishnan, 2014; Koelsch, 2012; Kraus & Banai, 2007; Krishnan, Gandour, & Bidelman, 2012b; Bidelman, Gandour, & Krishnan, 2011a; b; c; Kuhnis, Elmer, Meyer, & Jancke, 2013; Meyer, 2008; Moreno & Bidelman, 2014; Munte, Altenmuller, & Jancke, 2002; Patel & Iversen, 2007; Tervaniemi et al., 2009; Zatorre & Baum, 2012; Zatorre, Belin & Penhune, 2002; Zatorre & Gandour, 2008). Pitch specific EEG derived measures with high temporal resolution include the envelope and temporal fine structure information preserved in the fine-grained phase-locked neural activity reflected in the brainstem frequency following response (FFR), and the synchronized neural activity reflected in the transient components of the cortical pitch response (CPR). In this review, focus will be on the characteristics and differential sensitivity of scalp-recorded CPR, and its interplay with the brainstem representation of pitch-relevant information about the temporal attributes of pitch to further our understanding of how language experience shapes the distributed pitch processing network.

### **A novel cortical pitch-specific measure**

The study of pitch processing necessarily requires a measure that is pitch specific and sensitive to the temporal attributes of pitch. Earlier evaluations of pitch in the auditory cortex have utilized the magnetoencephalography (MEG) derived N100 (negative peak at 100 ms) component. However, this component is primarily a response to the onset of sound energy, and is not pitch-specific (Alku,

Sivonen, Palomaki, & Tiitinen, 2001; Gutschalk, Patterson, Scherg, Uppenkamp & Rupp, 2004; Soeta & Nakagawa, 2008; Yrttiahi, Tiitinen, May, Leino, & Alku, 2008). In order to isolate pitch-specific response from the onset response, a novel stimulus paradigm with an initial noise precursor followed by a pitch eliciting segment of iterated rippled noise (IRN) matched in peak-to-peak amplitude and overall spectral profile has been described (Krumbholz, Patterson, Seither-Preisler, Lammertmann, & Lutkenhoner, 2003). This paradigm has been shown to elicit a transient pitch specific response termed the pitch onset response (POR) at a latency of about 140-170 ms after the onset of the pitch segment. That this was a pitch-specific response was verified by the absence of POR for a reverse stimulus transition from pitch to noise. The MEG derived human POR is presumed to reflect synchronized cortical neural activity specific to pitch (Chait, Poeppel, & Simon, 2006; Krumbholz et al., 2003; Ritter, Gunter Dosch, Specht, & Rupp, 2005; Seither-Preisler, Patterson, Krumbholz, Seither, & Luktenhoner, 2006). For example, POR is more robust and response latency decreases as pitch salience increases. POR source analyses (Gutschalk, Patterson, Rupp, Uppenkamp & Scherg, 2002; Gutschalk et al., 2004; Krumbholz et al., 2003) indicates that anterolateral portion of Heschl's gyrus, the putative site for pitch processing (Bendor & Wang, 2005; Griffiths, Buchel, Frackowiak, & Patterson, 1998; Johnsrude, Penhune & Zatorre, 2000; Patterson, Uppenkamp, Johnsrude & Griffiths, 2002; Penagos, Melcher, & Oxenham, 2004; Zatorre, 1988), as the POR generator site. Human depth electrode recordings have also corroborated this finding (Griffiths et al., 2010; Schonwiesner & Zatorre, 2008). Given POR's sensitivity to pitch and its salience, and



**Figure 2.** Response waveform identifying the obligatory components P1, N1, P2 elicited by the precursor, and the cortical pitch response (CPR) components (Pa, Na, Pb, Nb, Pc, Nc) are shown on the left. Mean peak latency and amplitude of the response components are shown in the middle and right panels, respectively. Note the absence of any CPR components for a noise stimulus. Peak-to-peak amplitude are largest for Na-Pb and Pb-Nb. Data from Krishnan et al., 2014b; Krishnan et al., 2015a.

consistency across several studies, it offers an effective temporal window to evaluate the early sensory level representation of pitch-specific information at the level of the auditory cortex.

### Components of the EEG derived Cortical Pitch Response (CPR)

The EEG derived pitch specific response obtained using the POR paradigm (Krishnan et al., 2012a; 2012b; 2014b) consists of a series of biphasic components [labeled as Pa: 70–85 ms; Na: 125–140 ms; Pb: 200–215 ms; Nb: 265–280 ms; and Pc: 305–320 ms. (Figure 2)] in response to the rising lexical tone ( $T^2$ ), unlike the single Na peak observed for POR.

To distinguish POR from our EEG derived pitch response, we have named our response as the cortical pitch response (CPR).

Na, Pb, and Nb are the most robust response components that change with pitch-relevant stimulus parameters.

However, only Pb, Nb, and Pc show appreciable changes in latency with changes in stimulus parameters. These systematic changes in response latency and amplitude likely index changes in the temporal attributes of dynamic pitch stimuli

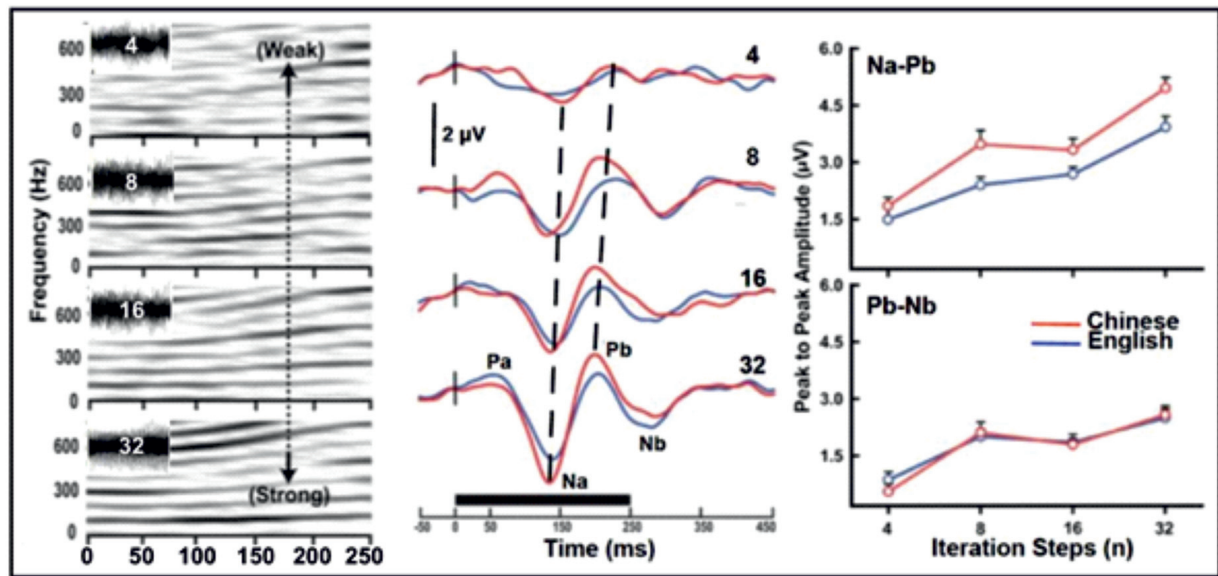
(Krishnan et al., 2014a; Krishnan et al., 2014b; Krishnan et al., 2014c).

### Differential Sensitivity of the CPR components to temporal attributes of pitch

Research from our laboratory has consistently shown that the components of the CPR are differentially sensitive to the temporal parameters of dynamic pitch stimuli including temporal regularity (relevant to pitch salience), pitch acceleration, pitch height, and pitch direction. We have clearly demonstrated that the neural encoding of these linguistically relevant pitch attributes is shaped by tonal language experience (Krishnan et al., 2012a; Krishnan et al., 2012b; Krishnan & Gandour 2014a; Krishnan et al., 2014b; Krishnan et al., 2014c; Krishnan et al., 2015a; Krishnan et al., 2015b; Krishnan et al., 2015c; Krishnan et al., 2016; Krishnan et al., 2017a; Krishnan et al., 2017b).

### Sensitivity to temporal regularity and pitch salience

For numerous complex sounds, including speech and music, pitch and its salience are closely related to the strength of the temporal periodicity in the stimulus waveform fine structure (Shofner, 2002; Yost, 1996a). Iterated rippled noise (IRN) is one such

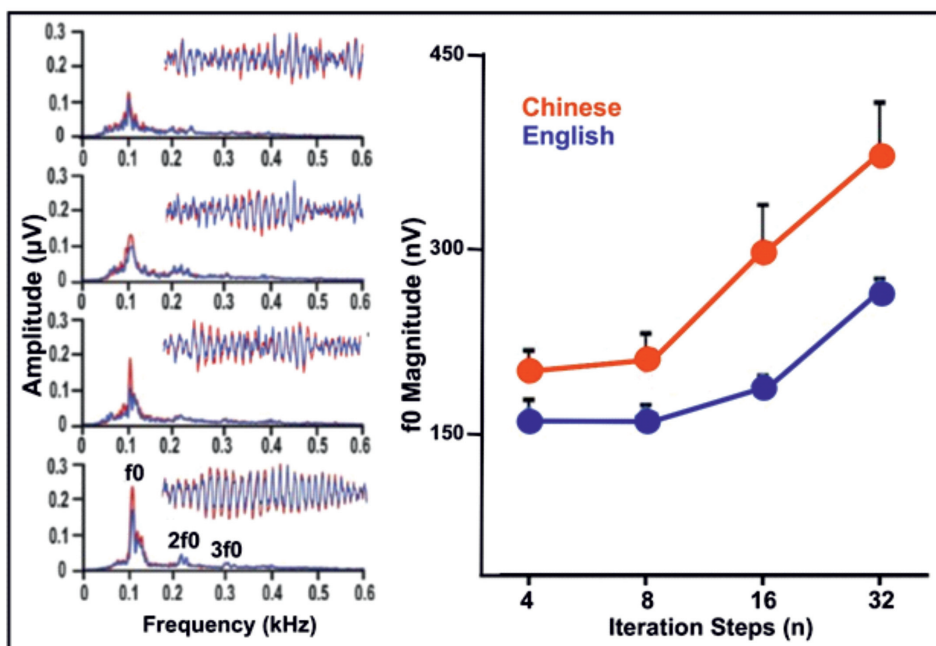


**Figure 3.** The effects of pitch salience on the CPR components. The left panel shows the spectrograms plotted as a function of IRN stimuli iterations steps [weak pitch (4) to strong pitch (32)]. The insets in the top left of each spectrogram shows the corresponding stimulus waveform for each iteration step. Note that as the iteration step increases, the temporal regularity of the stimulus increases, and the spectral bands become more robust. The middle panel shows the CPR response waveforms plotted as a function of iteration step for Chinese (Red) and English (Blue) listeners-response components are generally more robust for the Chinese. The right panel plots the mean peak-to-peak amplitude for Na-Pb (top right) and Pb-Nb (bottom right). Experience dependent effects are restricted to Na-Pb. Data from Krishnan et al., 2016.

complex sound wherein the temporal regularity of the waveform temporal fine structure can be systematically varied and hence the magnitude of pitch salience. IRN is generated by adding a delayed copy of random noise to the original noise and then repeating this delay-and-add process  $n$  times (Yost, 1996b). Increasing the number of iterations increases the temporal regularity of the noise and produces a spectral ripple in its long-term power spectrum (Figure 3, left panel).

The perceived pitch of IRN stimuli corresponds to the reciprocal of the delay, and the pitch salience increases with the number of iterations up to about 16-32 iterations (Patterson et al., 1996). This increase in pitch salience with increasing temporal regularity of the IRN stimulus has been shown to correlate well with an increase in pitch-relevant neural activity in both cortical and subcortical auditory neurons based on physiological (Griffiths et al., 1998; Sayles & Winter, 2007);

electrophysiological (Krishnan et al., 2016; Krumbholz et al., 2003; Soeta et al., 2005); functional brain imaging (Griffiths et al., 2001); and cortical recordings using intracranial electrode (Schonwiesner & Zatorre, 2008). Krishnan et al. (2016) carried out a systematic parametric evaluation of the nature of the interplay and coordination between the processing of pitch salience at the brainstem (FFR) and cortical (CPR) levels using the IRN version of the Mandarin lexical tone T<sup>2</sup>. Direct comparison of the FFR and CPR allowed them to evaluate if there was a transformation in the processing of pitch salience between the two levels of processing. Results (Figure 3, middle and right panels) showed that the peak latency of Na, Pb, and Nb decreased with increasing pitch salience for both groups, but the latency was relatively shorter in the Chinese across the increasing iteration steps. The Na-Pb and Pb-Nb response amplitude grew larger with increasing

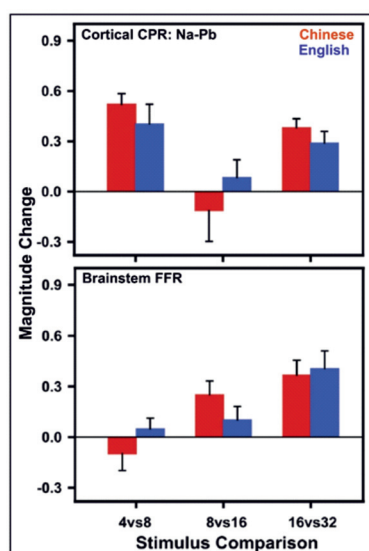


**Figure 4.** The effects of pitch salience on the FFR. The left panel shows the overlaid spectra, and FFR waveforms (inset) plotted as a function of iteration steps for the Chinese and English listeners. The mean f0 magnitude plotted as a function of iteration steps are in the right panel. Chinese show larger f0 amplitude across the iteration steps. Data from Krishnan et al., 2016.

pitch for both groups, but only Na-Pb showed an experience-dependent larger amplitude for the Chinese group. Like the cortical responses, the f0 magnitude of the concurrently recorded brainstem FFR response increased in amplitude with an increase in pitch salience (Figure 4). Direct comparison of the nature of relative change in response amplitude of the cortical CPR and the brainstem FFR with changes in pitch salience revealed differences for the Chinese group, suggesting an experience-dependent transformation in pitch processing from the brainstem to the cortical level. This transformation is presumably mediated by cortical level sensory and/or extrasensory influence on the cortical response.

Also, it is likely that bottom-up information from the brainstem exerts an influence on this transformation (Figure 5). These results taken together suggests that experience-shaped pitch mechanisms at the brainstem and cortical levels are

necessarily more sensitive to be able to encode linguistically relevant temporal attributes of pitch even when they are degraded appreciably. Finally, the observation of experience-dependent advantage in pitch salience for only Na-Pb suggests that processing of pitch and its salience are primarily indexed by pitch-relevant neural activity in only the Na-Pb time window. In contrast, the Pb-Nb time window likely indexes more dynamic temporal attributes of pitch, for example, the shape of pitch contour (Krishnan et al., 2015a; Krishnan et al., 2015b) and pitch acceleration (Krishnan et al., 2015c). Thus, experience-dependent effects are focused on specific temporal integration windows, represented by different CPR components, in which optimal processing occurs. More generally, we believe that pitch processing is hierarchical and involves both sensory and extrasensory effects. However, the relative influence of each effect depends on both language experience and the sensitivity of the pitch-



**Figure 5.** Mean normalized magnitude ratio of cortical (Na-Pb, top) versus brainstem (FFR, bottom) responses derived from successive iteration steps (I4-I8; I8-I16; I16-I32) in both Chinese and English groups. While the magnitude change is monotonic for the brainstem response, it is non-monotonic for the cortical response suggesting differences in pitch processing relevant to pitch salience at the two levels. Data from Krishnan et al., 2016.

relevant neural activity to pitch attributes in a given temporal integration window.

Comparison of Na-Pb amplitude changes, and behavioral pitch discrimination thresholds associated with changes in pitch salience reveals a strong association wherein neural response magnitude increases and pitch discrimination thresholds decreases with an increase in pitch salience indicating more robust neural encoding as pitch salience increases (Krishnan et al., 2012a). These results suggest that neural correlates of pitch salience, already seen in the early stages of pitch processing in the brainstem, may drive and maintain with high fidelity, the early cortical representations of pitch salience and may contain sufficient information for the development of perceptual pitch salience.

Finally, the observation of a robust experience-dependent right hemispheric preference for

processing pitch salience, as reflected in the Na-Pb amplitude, converges with extant literature that supports the role of the right hemisphere in processing linguistic as well as nonlinguistic pitch (Friederici & Alter, 2004; Friederici, 2011; Meyer, 2008; Zatorre & Gandour, 2008).

### Sensitivity to pitch acceleration

Pitch acceleration (the rate of change of pitch) in lexical tones is a salient perceptual cue for Mandarin listeners. Both brainstem FFR and cortical CPR responses reflect primarily sensory level processing, but they index pitch-relevant neural activity at different structural levels of the brain. Isolation of a single pitch parameter, like pitch acceleration here, allows us to examine the nature of the interaction between sensory and extrasensory effects, whose relative influence varies depending on language experience. Indeed, we have demonstrated that experience-dependent enhancement of the neural representation of pitch in the auditory brainstem is restricted specifically to rapidly accelerating segments of native pitch contours, without regard to speech or nonspeech contexts (Krishnan et al., 2009a; Krishnan et al., 2009b), and even for severely degraded stimuli (Krishnan et al., 2010a). Krishnan et al. (2010b) using a four-step acceleration continuum [lowest rate was equivalent to Mandarin Tone 2 ( $T^2$ ) and the fastest rate fell well outside the normal range of dynamic pitch (Figure 6, left panel)] demonstrated that Chinese listeners exhibited a more robust neural representation of pitch at the brainstem level compared to the English group. For both groups, neural periodicity strength was greater for acceleration rates within or proximal to natural speech relative to those beyond its range. Both groups showed decreasing pitch strength with

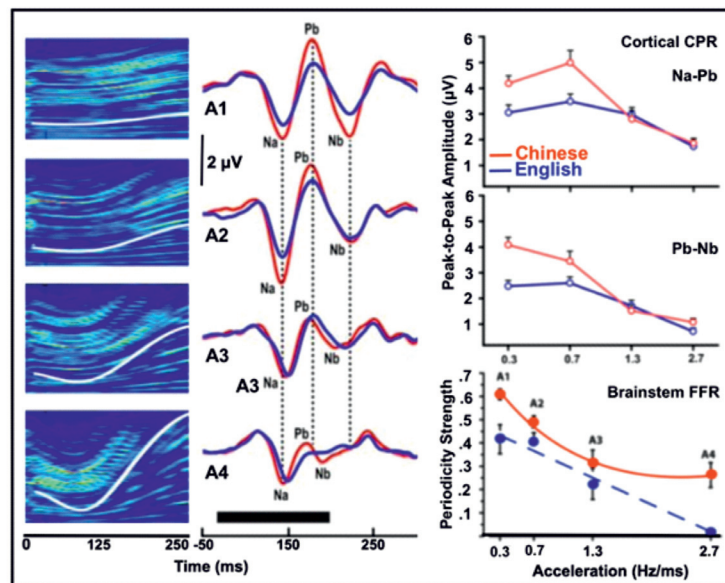
increasing acceleration rates, however, pitch representations of the Chinese group were more resistant to degradation (Figure 6, bottom right panel) due to rapid pitch acceleration. These results suggest that, for lexical tones, perceptually salient pitch cues influence brainstem pitch extraction not only in a domain general way but also to pitch accelerations that fall well beyond the range of dynamic pitch for a native listener. Similarly, we also observed that Na-Pb and Pb-Nb components of the CPR are also sensitive to variations in pitch acceleration presented in three within-category variants of T<sup>2</sup> (Krishnan et al., 2014a).

Using the same stimulus continuum as in Krishnan et al. (2010b), we examined how language experience influences processing of pitch acceleration rates at the cortical level (Krishnan et al., 2015c; 2017a) depicted in Figure 7. Our hypothesis was that both the response enhancement and hemispheric preference in the cortical pitch relevant neural activity is language-dependent and limited to native pitch acceleration rates. For acceleration rates beyond the normal pitch range, changes in CPR components are expected to reflect language independent auditory effects common for both groups. Consistent with this we observed that the Chinese group had shorter CPR latencies; greater amplitude for Na-Pb and Pb-Nb (Figure 6; middle and top panels) and a right hemispheric preference only to pitch contours with acceleration rates within the normal voice pitch range.

These findings suggest that the neural mechanism(s) mediating experience-dependent pitch processing for native acceleration rates are preferentially localized to the right auditory cortex. This enhancement of neural representation of native pitch stimuli and strong right hemispheric preference

of CPR components in the Chinese group is consistent with the notion that long-term experience shapes adaptive, distributed hierarchical pitch processing in the auditory cortex, and reflects an interaction with higher-extrasensory processes beyond the sensory memory trace. It is likely that the extrasensory influence may dominate or mask the purely sensory effects within a given temporal window. Thus, the different pattern of changes for native acceleration rates (A1 and A2) in the Chinese reflects an experience-dependent influence of extrasensory processes, while the similar pattern of activity for nonnative acceleration rates (A3 and A4) in both groups is more consistent with a purely sensory effect.

These findings point to experience-dependent enhancement of pitch attributes that varies depending on their functional roles in a particular language. These findings are also consistent with previous studies that have demonstrated experience-dependent neural plasticity in pitch processing at both subcortical and cortical levels of the brain (for reviews, Zatorre & Gandour, 2008; Krishnan et al., 2012a, Zatorre & Baum, 2012; Gandour & Krishnan, 2014; Gandour & Krishnan, 2016). In this study, we infer that extrasensory processes are overlaid on sensory processes to modulate long-term, experience driven, adaptive pitch mechanisms at early sensory levels of pitch processing in the auditory cortex. This is accomplished by sharpening response properties of neural elements to enable optimal representation of temporal attributes of pitch contours that are behaviorally relevant. That is, the amplitude may be reflecting the robustness of the underlying pitch-relevant neural activity within the temporal windows being utilized to process the various temporal attributes of pitch.



**Figure 6.** The effects of pitch acceleration on the cortical CPR and brainstem FFR. In the left panel the spectrograms of the four stimuli (A1, A2, A3, A4) show the change in the trajectory of the rising pitch contours as pitch acceleration is increased. Grand average CPR waveforms of the Chinese (C) and English (E) groups are plotted for the four acceleration rates (middle panel). Na-Pb and Pb-Nb amplitudes are more robust for the Chinese as compared to the English especially for the slower acceleration rates (A1, A2). Solid black horizontal bar indicates the duration of each stimulus. Dotted vertical black lines follow the latency changes of the components with increasing pitch acceleration. Mean Na-PB and Pb-Nb amplitude (top two right panels) decrease with increasing pitch acceleration. For both components experience dependent enhanced amplitude is limited to the two slower acceleration rates that fall within the native range. Periodicity strength of the brainstem responses (bottom right panel) also show a similar pattern, but the experience dependent advantage is maintained across all four stimuli. Data from Krishnan et al., 2010b; Krishnan et al., 2015c.

### Sensitivity to pitch acceleration: Brainstem vs cortical representation

Since experience-dependent enhancement of sensitivity to pitch acceleration is already observed in the brainstem pitch representation (Krishnan et al., 2010b), it is likely that cortical pitch mechanisms may be reflecting, at least in part, this enhanced pitch input from the brainstem (cf. Bidelman et al., 2014). However, the pattern of stimulus effects reflected in the cortical CPR components differ from those observed in the FFR at the level of the brainstem. Unlike the CPR, Chinese showed stronger pitch representation than English for all stimuli in the continuum at the brainstem (Krishnan et al., 2010b). Thus, the experience-dependent effect in the brainstem is not restricted to just native acceleration rates as observed at the cortical level. This targeted experience-dependent effect suggests enhanced

selectivity to linguistically relevant pitch contours at the cortical level of pitch processing (see brainstem vs cortical comparisons in the right panels of Figure 6).

### CPR may reflect both sensory and extrasensory modulation.

Pitch relevant neural activity reflected in the CPR components may be reflecting both experience-dependent extrasensory, and experience-independent sensory effects (Krishnan et al., 2015a, Krishnan et al., 2015b). Extrasensory here refers to neural processes at a higher hierarchical level and not simply the sensory level processing of the temporal attributes of pitch in the primary auditory cortex. Analyzed sensory memory (Cowan, 1984, 1987, cf. Xu et al., 2006), which preserves fine-grained representation of different temporal

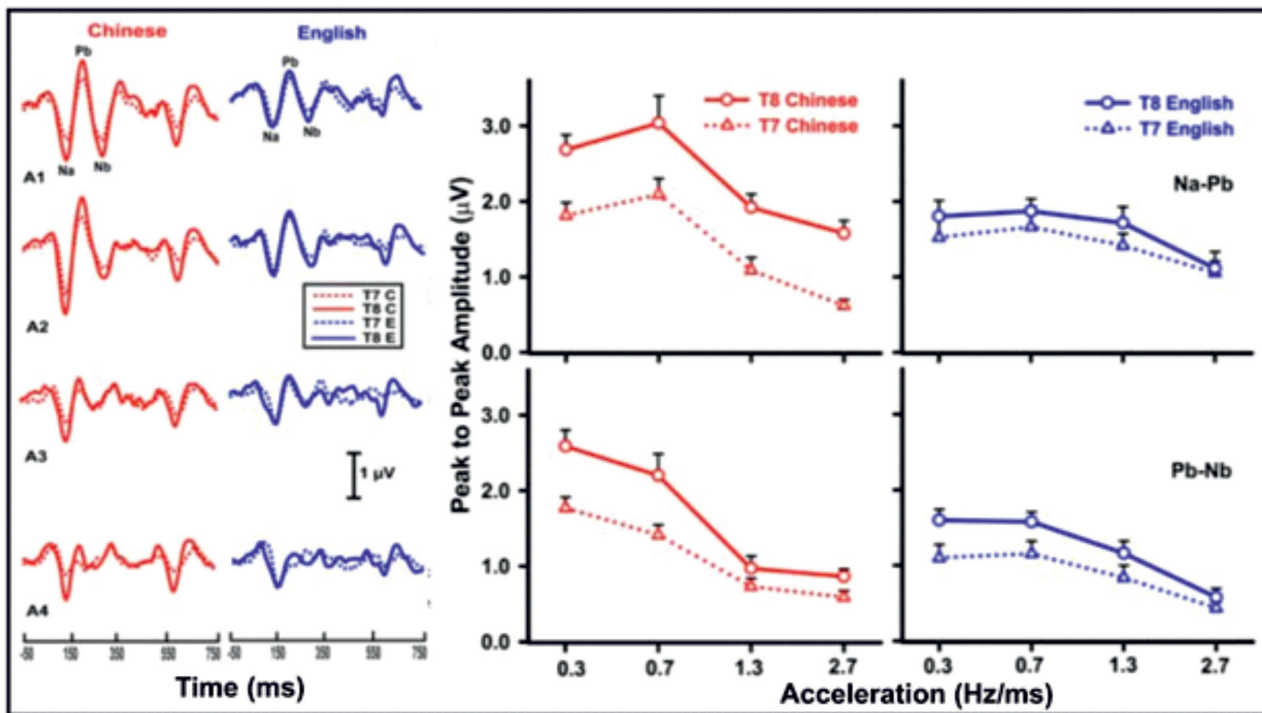


Figure 7. The left panel illustrates the grand averaged CPR waveforms plotted as a function of acceleration rate for the two groups at electrode locations T7 and T8. CPR waveforms show a right-sided preference (T8 > T7) for the Chinese group only and limited to the slower acceleration rates characteristic of natural speech (A1, A2). Mean peak-to-peak amplitude Na-Pb (Top right) and Pb-Nb (bottom right) amplitude show a language-dependent effect (C > E) over the right temporal site (T8) elicited by A1 and A2, the two pitch stimuli with native-like acceleration rates. Error bars =  $\pm 1$  SE. C, Chinese; E, English. Data from Krishnan et al., 2015c; Krishnan et al., 2017a.

attributes of pitch (for example, pitch salience, pitch acceleration could be a likely candidate. This memory should be distinguished from the initial, sensory memory trace and later cognitive processes with their associated short-and long-term memory stores. Its lifetime is on the order of seconds. In this four-store model of memory, information is encoded in a hierarchical manner but short-term and analyzed sensory memory can be processed in parallel. Since our experimental task does not require attention, short-term or long-term memory, or decision-making, it is unnecessary to invoke short-term memory. However, any language-dependent effect is also a memory effect. As soon as a sensory signal engages a stored representation, there is an interesting interaction based on the nature of that representation. In our case, that stored representation

resides in analyzed sensory memory, which cannot be attributed simply to the sensory memory trace. Otherwise, we would expect no differences across language groups. Hasson et al. (2015) propose a biologically motivated process memory framework, in contrast to traditional encapsulated stored memory, to explain information processing in cortical neural circuits. Process memory refers to the integration of active traces of past information that are used by a neural circuit to process incoming information in the present moment. To influence ongoing processing, the prior information must be in an active state, i.e., neural activity containing information about stimulus in each circuit integrated over the time course of the event. In our case, that would include analyzed sensory memory and/or long-term representation(s) of the stimulus that is

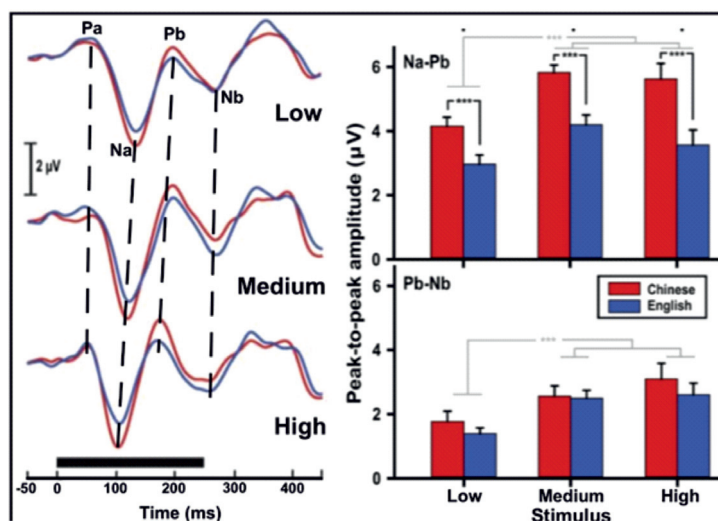
activated during the processing of the incoming information. Active here means, either a sustained increase in firing rate or information preserved in a neural circuit via short-term calcium-mediated synaptic facilitation (Mongillo et al., 2008). The integration time scales (i.e., temporal receptive windows in which prior information from an ongoing stimulus can influence the processing of newly arriving information vary in a hierarchical fashion across the cerebral cortex, with shorter (milliseconds to seconds) timescales in sensory regions and gradient of lengthening timescales (seconds to minutes) in higher-order cortices. Our CPR responses would be activated in the early stages of this processing memory hierarchy and utilize short temporal receptive windows where the neural dynamics are more rapid.

### **Sensitivity to pitch height**

Pitch height is a robust continuous perceptual attribute associated with the voice fundamental frequency ( $f_0$ ) that scales pitch from low to high. It increases with increase in frequency of  $f_0$  and offers a strong cue for the segregation of sound sources (Roffler & Butler, 1968; Shepard, 1982; Krumhansl, 1990; Melara & Marks, 1990). MEG and EEG studies have consistently shown that latency of different auditory evoked potentials, including the pitch specific cortical response (POR), decrease with increase in pitch of pure tones (Roberts & Poeppel, 1996; Seither-Preisler, Krumbholz, & Lutkenhoner, 2003); synthetic speech (Poeppel & Roberts, 1996); bandpass-filtered harmonic tones (Ragot & Lepaul-Ercole, 1996); and IRN (Krumbholz, et al., 2003; Ritter et al., 2007). The EEG derived POR (same as Na of the CPR) also showed decrease in response latency with increasing frequency (Bidelman, 2015). The absence of stimulus effects

for amplitude in this study maybe due to the constant rate of pitch acceleration across stimuli (cf. Xu, Krishnan, & Gandour, 2006; Krishnan, Gandour, Bidelman & Swaminathan, 2009a; Krishnan, Gandour & Suresh, 2014b). Collectively, these results indicate that extraction of temporal pitch change, such as pitch height, requires temporal integration. Functional neuroimaging studies have shown that planum temporale is specifically activated by pitch height changes (Griffiths & Warren, 2002; Warren, Uppenkamp, Patterson, & Griffiths, 2003).

In Mandarin, pitch height differences produce shorter peak latencies compared to latency changes based on pitch contour. Mandarin lexical tones varying in height, when changing from male to female to a child's voice pitch, will still exhibit identical contour shape and pitch acceleration. In addition, Mandarin speakers show relatively greater sensitivity to changes in pitch acceleration and pitch contour compared to pitch height. We (Krishnan et al., 2017b) investigated language experience effects on the representation of dynamic, time-variant pitch height information as preserved in simultaneously recorded responses in the brainstem and auditory cortex (cf. Krishnan, Bidelman, Smalt, Ananthakrishnan & Gandour, 2012a, steady-state pitch). CPR and FFR responses were recorded by systematically varying pitch height along a continuum using an IRN homolog of a Mandarin lexical tone. Since changes in rates of acceleration are fixed throughout stimulus duration, we hypothesized that language-dependent effects on pitch height (cf. pitch salience, Krishnan, Gandour, & Suresh, 2016) will be restricted to the earlier CPR time window (Na–Pb). Consistent with previous reports, the latency of CPR components decreased as pitch height increased suggesting, at least in part, that the traveling



**Figure 8.** Grand averaged CPR waveforms (left) for the Chinese, (red) and English (blue) plotted for the three pitch height conditions (Low, Middle, and High). For all three conditions the response components for the Chinese appear to be larger than the English. Vertical dashed lines show the shortening of latency of the components with increasing pitch height. The solid black bar at the bottom indicates the duration and temporal position of the pitch eliciting segment in the stimulus. Mean amplitude of the CPR components (Na-Pb, right panel, top row; and Pb+Nb bottom row) are displayed for both the groups. Na-Pb clearly shows an experience dependent effect across stimuli. Pb-Nb only show a stimulus effect. Data from Krishnan et al., 2017b.

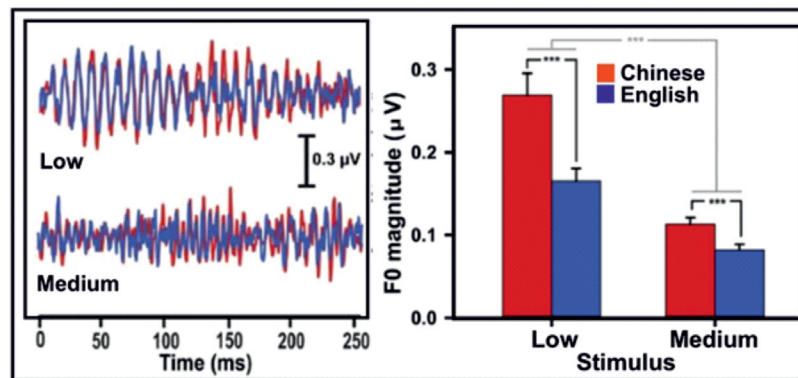
wave delay along the cochlear partition and tonotopic organization in the auditory cortex (Pantev, Hoke, Lutkenhoner, & Lehnertz, 1989; Pantev, Bertrand, Eulitz, Verkindt, Hampson, Schuierer, & Elbert, 1995; Bidelman & Grall, 2014). However, the much longer CPR latencies associated with IRN stimuli likely reflect longer integration times required for pitch estimation. Pitch specific computations could at the least cause four times the delay of the of IRN stimuli (Krumbholz et al., 2003). Another view is that the tonotopic map in the primary auditory cortex is a periodotopic map (Pantev et al., 1989; Pantev et al., 1995). It is not clear, however, how periodotopic maps may contribute to pitch processing (cf. Langner, Sams, Heil, & Schulze, 1997).

The increase in Na-Pb, and Pb-Nb amplitude with pitch height for both groups (Figure 8). is consistent previous studies. Ritter et al., (2005), using IRN stimuli with either 2 or 8 iteration steps, also observed an increase in POR amplitude with pitch height. POR amplitude also increases with decrease

in delay (therefore higher pitch) of IRN stimuli from 16 ms (64 Hz) to 8 ms (125 Hz); with much shorter delays being ineffective (Krumbholz et al., 2003).

The increase in CPR amplitude with pitch height likely reflects an increase in the temporal synchronization of pitch-relevant neural activity as the temporal window for pitch extraction decreases. A language-dependent amplitude increase (Chinese > English) and a right hemisphere preference were restricted to Na-Pb. At the level of the brainstem (Figure 9), the f<sub>0</sub> amplitude was greater for the Chinese across stimuli and decreased with increasing pitch height for both groups (Batra, Kuwada, & Maer, 1986; Hoormann, Falkenstein, Hohnsbein & Blanke, 1992; Krishnan, 2002), consistent with reduced neural phase-locking with increasing frequency (Rose, Brugge, Anderson, & Hind, 1967; Lavine, 1971).

Collectively, these findings suggest the operation of two distinct, language independent

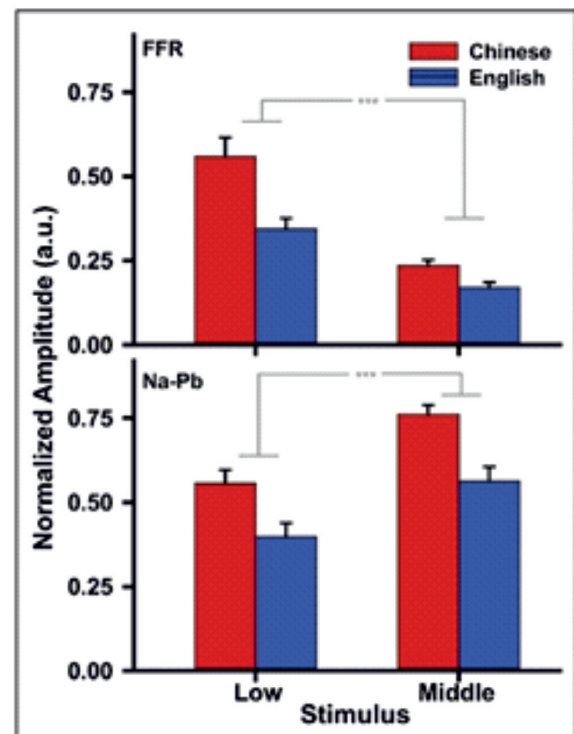


**Figure 9.** Grand averaged FFR waveforms (left) for the Chinese, (red) and English (blue) plotted for two pitch height conditions (Low, and Middle). For both conditions the Chinese waveforms appear to be more robust compared to the English. Mean f0 magnitude shown on the right shows the f0 magnitude for the Chinese was significantly greater than for the English for both conditions. Data from Krishnan et al., 2017b.

sensory level neural mechanisms. One, a neural phase locking based temporal code at the brainstem level and the other a discharge rate-based place code at the cortical level.

The enhanced pitch-relevant neural activity at both brainstem and cortical levels in the Chinese group, likely reflects a neural response sharpening to ensure optimal representation of behaviorally-relevant pitch attributes and further strengthens our previous observations of language experience shaped pitch representation at subcortical and cortical levels (for reviews, see Krishnan, Gandour, & Bidelman, 2012b; Gandour & Krishnan, 2014; Krishnan & Gandour, 2014c; Gandour & Krishnan, 2016). Furthermore, CPR and FFR responses exhibited different patterns of relative changes in magnitude common to both groups (Figure 10). While CPR amplitude increased, FFR amplitude decreased with increasing pitch height. We interpreted these differences in the response patterns to suggest transformed neural mechanisms for pitch extraction at the cortical level compared to the brainstem,

In summary, changes in pitch height elicit responses that are either experience-dependent, or



**Figure 10.** Mean normalized amplitude of FFR (top) and CPR Na-Pb component (bottom) for each group (Chinese, English). In general, response amplitudes are larger for Chinese compared to English. For Na-Pb, amplitude for the middle pitch height is larger than the low pitch height. In contrast, the f0 amplitude of the brainstem FFR is greater for the low pitch height compared to the middle pitch height. While the increase in Na-Pb magnitude with pitch height suggests an increase in synchronized neural activity in a rate-based encoding scheme at the cortical level; the decrease in FFR f0 magnitude with increasing pitch height reflects a decrease in neural phase locking with increasing frequency in a temporal encoding scheme at the brainstem level. Data from Krishnan et al., 2017b.

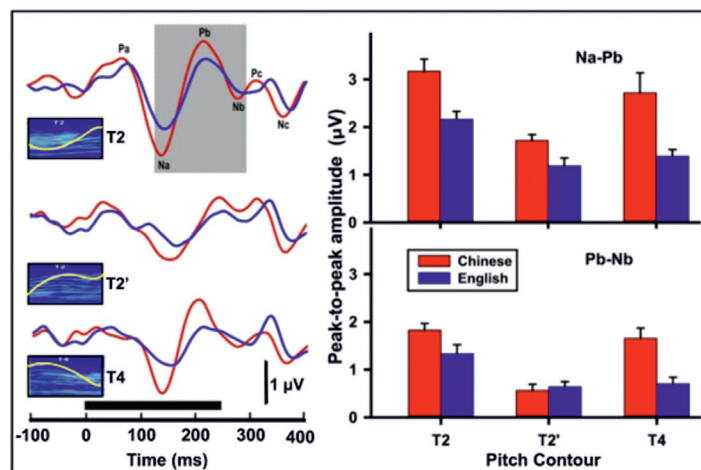
experience-independent. The enhancement of pitch-relevant neural activity represents, in our view, an extrasensory (processes at a higher level) modulation of early sensory pitch mechanisms in the brainstem and auditory cortex (for additional discussion, see Krishnan, Gandour, & Suresh, 2016, p. 111). These adaptive, cortical pitch mechanisms presumably sharpen neural representation of temporal attributes of pitch. Consistent with our theoretical framework for experience-induced neural plasticity (Krishnan, Gandour, & Bidelman, 2012a), the experience-dependent effect observed at the cortical level may reflect, at least in part, enhanced fine-grained output from brainstem pitch mechanisms that are themselves influenced by language experience. This coordination between the auditory brainstem and cortex has also been reported in studies of long-term language experience with French syllables (Intartaglia, Whiteschwoch, Meunier, Roman, Kraus, & Schon, 2016); and older musicians' experience with English vowel perception (Bidelman & Alain, 2015).

Whenever pitch acceleration or the shape of pitch contours is manipulated, experience-dependent enhancement applies to both Na–Pb and Pb–Nb (Krishnan, Gandour, Ananthakrishnan, & Vijayaraghavan, 2015a; Krishnan, Gandour, & Suresh, 2015a; b). If, on the other hand, changes in acceleration or contour shape are held constant, language-dependent effects are restricted to the earlier Na–Pb time window only (e.g., pitch salience; Krishnan, Gandour, & Suresh, 2016). Herein, we manipulated only pitch height with no change in pitch acceleration or shape. Like pitch salience, experience-dependent effects elicited by pitch height is restricted to Na–Pb because the Na–Pb time window optimally indexes neural processing relevant to the estimation of pitch and its strength (e.g., pitch salience, pitch height). The Pb–Nb time window,

on the other hand, may index other dynamic, time-variant pitch attributes. Thus, experience may selectively target specific time windows to enhance specific CPR components (in specific temporal windows) that best indexes a given temporal attribute of pitch. These findings collectively suggest that pitch processing along the auditory neuraxis requires a well-coordinated interplay between sensory and extrasensory processes. The weighting of contributions from each depends on both the language experience and neural sensitivity to pitch attributes within a given temporal integration window. The right hemispheric targeting of the experience-dependent effect observed for only Na–Pb amplitude, is consistent with strong empirical evidence supporting a more fine-grained processing of pitch-relevant information in the right hemisphere for both linguistic and nonlinguistic pitch (Meyer, 2008; Zatorre and Gandour, 2008; Friederici, 2011).

### **Sensitivity to pitch contour direction**

Pitch contour also is important for the perception of lexical tones (for reviews, Gandour, 1994; Gandour & Krishnan, 2014, 2015). Indeed, in tone languages, the primary auditory correlate of lexical tone is based on variations in pitch contour and not pitch height (Gandour, 1983; Huang & Johnson, 2011). In English however, the opposite is true. This differential weighting for pitch contour and pitch height is sustained even when trained Mandarin and English speakers are asked to make pairwise comparison ratings of Cantonese lexical tones (Francis, Ciocca, Ma, & Fenn, 2008). Mismatch negativity (MMN) responses evoked by Mandarin tones show that Chinese listeners are more sensitive to pitch direction than height as compared to English listeners (Chandrasekaran, Gandour, & Krishnan,

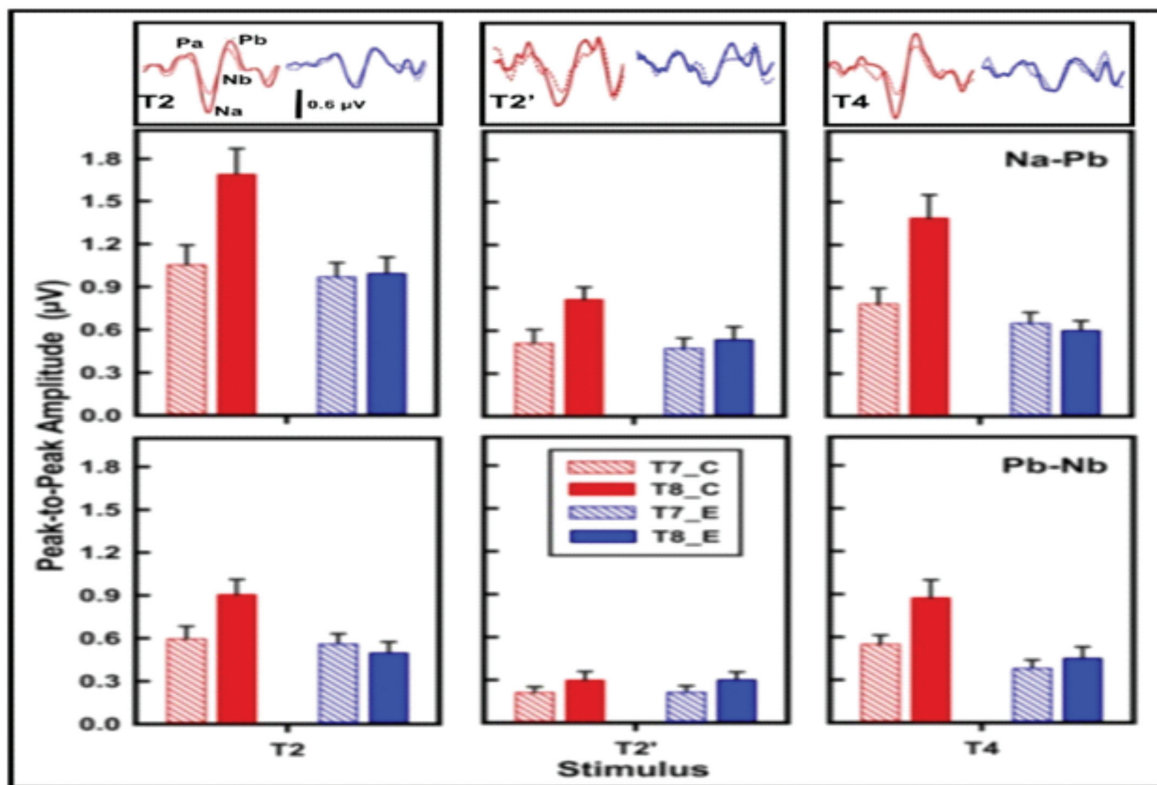


**Figure 11.** Spectrograms (inset to the left of each grand averaged CPR waveform) and the three pitch contours ( $T^2$ ,  $T^{2'}$ ,  $T^4$ ). For all stimuli, clear rising or falling spectral bands are seen corresponding to the harmonics of the fundamental frequency. While  $T^2$  and  $T^4$  represent native pitch contours,  $T^{2'}$  does not occur in the Mandarin tonal space. The pitch contours are phonetically distinguished by changes in the location of peak acceleration (early vs late). Grand averaged waveforms of the Chinese and English groups show that Na, Pb, and Nb (highlighted in gray in the top panel) are the most robust pitch-relevant components across stimuli with the Chinese showing larger amplitude particularly for native pitch contours ( $T^2$  and  $T^4$ ) and late acceleration peaks. Changes in pitch direction are also clearly seen in the spectrograms. The duration of each stimulus is indicated by the solid black horizontal bar. Mean peak-to-peak amplitude of CPR components Na-Pb (top right panel) and Pb-Nb (bottom right panel) are plotted as a function of stimulus type. Chinese exhibit greater Na-Pb amplitude than English across stimuli;  $T^2$  and  $T^4$  amplitudes are greater than  $T^{2'}$  for both groups. Chinese also show greater Pb-Nb amplitude for pitch contours with a late acceleration peak ( $T^2$ ,  $T^4$ ) compared to  $T^{2'}$  which has an early acceleration peak. English listeners, on the other hand, show greater amplitude of  $T^2$  relative to  $T^4$  in addition to  $T^{2'}$ . Error bars indicates  $\pm 1$  SE. Data from Krishnan et al., 2015b.

2007; Chandrasekaran, Gandour, & Krishnan, 2009). Also, the time course of these pitch attributes, as reflected by the MMN, are also different.

We recorded CPRs in response to three dynamic, curvilinear nonspeech pitch contours varying in *pitch direction* and *temporal location of the turning point* to examine how language experience influences the pitch processing of dynamic contours at the cortical level (Krishnan et al., 2015b) Mandarin lexical *Tone*<sup>2</sup> (rising) and *Tone*<sup>4</sup> (falling); and a nonnative flipped variant of *Tone*<sup>2</sup>, *Tone*<sup>2'</sup> were used (see Figure 11 inset). Neural activity relevant to pitch showed distinct language experience induced changes between the groups (Chinese vs. English; pitch patterns (native vs. nonnative); changes in acoustic attributes (rising vs. falling); and location of peak acceleration (early vs. late) of dynamic time-varying pitch contours. Pb-

Nb amplitude was greater in Chinese compared to English for pitch contours that occur in the Mandarin tonal space as compared to a nonnative pitch contour (Figure 11, left and right panels). Both Na-Pb and Pb-Nb at temporal sites pooled across stimuli showed a right hemispheric preference for Chinese only (Figure 12); Chinese Na-Pb response amplitude to  $T^2$  &  $T^4$  was greater than English in the right hemisphere only; amplitude for  $T^2$  &  $T^4$  was greater than  $T^{2'}$  in Chinese only. As reflected by Pb-Nb at Fz, Chinese amplitude was larger than English in response to  $T^2$  &  $T^4$ ; and  $T^2$  &  $T^4$  were larger than  $T^{2'}$ ; whereas for English,  $T^2$  was larger than  $T^{2'}$  and  $T^4$ . Regardless of component or hemisphere, Chinese responses were larger in amplitude than English across stimuli at the frontal electrode sites (F3/F4). For either group, responses to  $T^2$  &  $T^4$  were larger than  $T^{2'}$ .



**Figure 12.** Grand averaged CPR waveforms (top inset) for the two language groups [Chinese (Red), English (Blue)] recorded at electrode sites T7 (dashed) and T8 (solid) for each of the three stimuli ( $T^2$ ,  $T^{2'}$ ,  $T^4$ ). For Chinese there appears to be a clear right hemispheric preference for  $T^2$  and  $T^4$ -native pitch contours with late acceleration peaks. Consistent with this, both Na-Pb Pb-NB amplitude show a RH preference in response to  $T^2$  and  $T^4$  for the Chinese only (a language dependent effect). Further, responses to these native contours are larger than  $T^{2'}$  only in the RH for the Chinese group. Error bars =  $\pm 1$  SE. C, Chinese; E, English. Data from Krishnan et al., 2015b.

These findings suggest that early sensory level mechanisms of pitch in the right auditory cortex, sensitive to several temporal attributes of time-varying pitch, are language independent and therefore common to both groups. The language experience dependent effects observed in the Chinese reflect *language-dependent* modulation of those temporal attributes of pitch contours that provide perceptually robust cues for recognition of native tones. Thus, sensory, and extrasensory effects in early cortical pitch processing are differentially weighted. Consistent with this view, experience-dependent response enhancement may reflect either a purely sensory effect, or more likely a predominance of sensory influences over extrasensory. We argue that this experience-

dependent effect demonstrates that extrasensory components may predominate over sensory components in their influence within a given temporal integration window or, in other words, mask purely sensory effects. If purely sensory, then we cannot account for why we do not observe the same stimulus pattern in the English group. We expect extrasensory influences to target, especially those pitch attributes that are perceptually salient in a particular language.

It is not accidental that extrasensory effects emerge in Pb-Nb instead of Na-Pb. In a behavioral experiment using excised segments from f0 contours of Mandarin tones (Whalen & Xu, 1992), tonal recognition is shown to be markedly better in the

later segments of portions of Tone<sup>2</sup> and Tone<sup>4</sup>. It is precisely those portions that coincide with a large change in f<sub>0</sub> at the brainstem level. Examination of brainstem responses elicited by speech, and nonspeech stimuli shows stronger pitch representation in Chinese compared to English for the later, rapidly changing portions of Tones<sup>2&4</sup> (Krishnan et al., 2009a; Krishnan et al., 2009b). Though we are unable to temporally match portions of f<sub>0</sub> contours with CPR components in the current experimental design, we speculate that Pb-Nb is targeting those same perceptually relevant portions of T<sup>2</sup> and T<sup>4</sup>. The neural bases of enhancement in sensitivity may involve sharper tuning, increased neural synchronization, and improvement in synaptic efficiency - all three combine to optimize neural representation of behaviorally relevant, dynamic pitch contours. Our experimental paradigm is pitch specific and does not have any task demands.

As indicated before, our findings converge with extant literature that attests to the crucial role of the RH in the processing of linguistic as well as nonlinguistic pitch (Zatorre et al., 2002; Friederici & Alter, 2004; Hyde et al., 2008; Meyer, 2008; Zatorre & Gandour, 2008). The RH preference of pitch mechanisms in the auditory cortex for the Chinese is in line with the view that the analysis of suprasegmental parameters of speech (Friederici, 2011) specifically involves the RH. Like this RH preference for processing linguistic pitch, processing of the more salient consonantal musical stimuli in musicians also show a RH preference as reflected in the POR (Bidelman & Grall, 2014). Collectively, these results suggest that the RH is preferentially recruited for optimal representation are perceptually relevant temporal attributes of pitch in a domain general manner.

The question arises whether language experience shaped RH preference at early cortical stages of processing is driven by both extrasensory influences, and purely acoustic properties of the stimuli. Extrasensory here refers to higher hierarchical level neural processes beyond the purely sensory processing of acoustic attributes of the stimulus. Analyzed sensory memory is a likely candidate that provides fine-grained stored representations of pitch attributes at this early sensory cortical level of processing (Cowan, 1984; 1987; cf. Xu et al., 2006). This memory process (distinct from the initial, sensory memory trace, and later cognitive processes with their associated memory stores [e.g., short-term memory]) contains analyzed sensory codes including information about the different temporal attributes of pitch (for e.g., pitch height, pitch direction, and acceleration).

### **Effects of acoustic properties of Stimuli in early cortical pitch processing**

The systematic latency differences in our CPR components for different pitch attributes point to the utilization of effective temporal integration windows. For both groups, T<sup>2'</sup> elicited a longer latency than T<sup>2</sup> or T<sup>4</sup> for components Na and Pb. This increased latency for T<sup>2'</sup> likely reflects reduced temporal sensitivity and/or desynchronization of neural activity to a rapidly rising portion of the pitch contour that occurs temporally earlier for T<sup>2'</sup> but much later for T<sup>2</sup> and T<sup>4</sup>. In the English, Na latency is longer compared to Chinese for T<sup>2</sup> and T<sup>4</sup>. Taken together, these findings suggest that the duration of the temporal integration window may be differentially affected by both the *temporal location* of the *acceleration peak and pitch direction*. With respect to the amplitude of CPR components, Chinese exhibit greater sensitivity to both pitch

direction and location of acceleration peak. As indexed by Na-Pb, the rising pitch contour ( $T^2$ ) evokes a larger amplitude than the falling ( $T^4$ ). This differential sensitivity to pitch direction is also observed at multiple levels of the auditory system using various experimental techniques (human psychophysical, multidimensional scaling, electrophysiological, cochlear microphonics, 8th nerve compound action potentials, and responses of the ventral cochlear nucleus). The relatively smaller amplitude observed for  $T^{2'}$ , also a rising pitch contour but with an early temporal onset of an increase in acceleration, likely reflects biomechanical constraints on the velocity of laryngeal movements in tone production (Erickson, 1976; Ohala, 1978; Xu & Sun, 2002). Clearly, it cannot be due to differences in acceleration rate per se because  $T^2$  and  $T^{2'}$  are identical in acceleration rate. It must therefore be attributed to its early temporal location near the onset of  $T^{2'}$  which likely reflects differences in neural synchronization when a rapid rise in pitch occurs earlier as compared to later in the pitch contour. Differences in pitch direction notwithstanding, the two native stimuli with a later acceleration peak ( $T^2$ ,  $T^4$ ) have a larger amplitude than  $T^{2'}$ , even though they exhibit a stark difference in pitch direction. The group x stimulus interaction observed for Pb-Nb, suggests a *differential weighting of sensory and extrasensory influences* depending upon one's language experience. In the Chinese, the response amplitude for the two lexical tones ( $T^2$ ,  $T^4$ ) are greater than for  $T^{2'}$ . In contrast, the English show greater response amplitude for  $T^2$  compared to  $T^{2'}$  and  $T^4$ . The amplitude behavior in the English may be attributed to differences in auditory sensitivity to pitch direction ( $T^2 > T^4$ ) and location of peak acceleration ( $T^2 > T^{2'}$ ). Similarly, the Chinese amplitude behavior also shows auditory sensitivity

to the location of peak acceleration, this specific pitch attribute also segregates native lexical tones ( $T^2$ ,  $T^4$ ) from a nonnative pitch stimulus ( $T^{2'}$ ). However, if these effects are strictly sensory, we would expect parallel response behavior, without regard to language experience. To the contrary, we observe that the Chinese amplitude is greater than English in response to only the two native Mandarin pitch contours. The lack of an experience dependent effect for  $T^{2'}$  agrees with previous studies which also failed to show experience-dependent enhancement of pitch-relevant neural activity for nonnative pitch contours at the level of the cerebral cortex (Chandrasekaran et al., 2009,  $T^2$ ; Krishnan et al., 2014, flat & linear rising ramp) and at the level of the auditory brainstem (Krishnan et al., 2009a, linear rising & trilinear rising ramps,  $T^{2'}$ ). These results force us to invoke the influence of extrasensory effects on pitch processing that are targeted at perceptually relevant features of Mandarin lexical tones. Even though  $T^2$  (late acceleration peak) elicits a larger amplitude than  $T^{2'}$  (early acceleration peak) in both groups, the amplitude of  $T^2$  is still larger in the Chinese group. This finding is consistent with the view expressed earlier that the fundamental neural mechanism is the same for Chinese and English listeners alike, but the long-term language experience shaped pitch mechanisms in Chinese show enhanced sensitive to temporal attributes of pitch that are behaviorally relevant for linguistic pitch processing. Because enhanced sensitivity to time-varying dimensions of pitch (e.g., acceleration) is already present in neural activity at the level of the brainstem (Krishnan & Gandour, 2009c; Krishnan et al., 2012b, reviews), it seems plausible that cortical pitch mechanisms may be reflecting, at least in part, this enhanced pitch input from the brainstem (Bidelman et al., 2014).

Collectively, these findings highlight that cortical pitch response components are differentially modulated by experience-dependent, temporally distinct but functionally overlapping weighting of sensory and extrasensory effects on pitch processing of lexical tones in the right temporal lobe and, more broadly, are consistent with a distributed hierarchical predictive coding process.

## Conclusions

By systematic parametric manipulation of several dynamic temporal attributes of pitch we are able to determine that the differential sensitivity of the CPR components to different temporal attributes of pitch enable us to advance our understanding of pitch processing and how it is influenced by long-term language experience. While the CPR *Na-Pb time window* indexes pitch, pitch strength, pitch height, and differential sensitivity to pitch contours varying in direction and location of the onset of acceleration; the *Pb-Nb time window* is specifically sensitive to changes in pitch acceleration. Both these components are shaped by language experience. The CPR components enable us to disentangle pitch-relevant neural activity that reflects early purely sensory level, language-independent pitch processing from a language experience dependent pitch processing that may additionally reflect the influence of extrasensory modulation. A language-dependent effect is demonstrated by enhanced sensitivity to several temporal attributes of pitch in the Chinese group regardless of the level of brain structure, and a RH preference for processing pitch-relevant information indexed by Na-Pb and Pb-Nb temporal windows. Adaptive mechanisms in the RH afford more fine-grained processing of linguistically relevant, temporal pitch attributes. A similar pattern of changes in CPR latency/amplitude and FFR

magnitude point to shared, neural mechanisms underlying pitch encoding independent of language experience at both levels of processing. The experience-dependent enhancement of the CPR components and the RH preference suggests extrasensory modulation of sensory processes is targeted to response components and/or temporal windows that best index a specific temporal attribute of pitch. Different patterns of changes in the CPR and FFR responses may imply a transformation in the processing of pitch-relevant information at the cortical level compared to the brainstem level. Top-down influences may selectively gate inputs to both cortical and subcortical structures to optimize the neural representation of behaviorally relevant attributes of the stimulus. The concurrent recording of brainstem and cortical pitch-relevant responses may also provide a new analytic window to examine the online interplay between feedforward and feedback components in the processing of pitch-relevant information along the processing hierarchy, and how it is shaped by language experience. Future complementary studies using MEG and fMRI studies will be crucial to determine the anatomical sources of the pitch specific cortical responses, and the organization of the distributed pitch processing network in the brain, respectively. The challenge is to design experiments that can capture in a robust the functional organization and operational characteristics of what we believe is a dynamic adaptive distributed (cortical and subcortical levels) hierarchical processing network. The results of these experiments would be essential to develop a solid theoretical framework to understand both the nature of the interplay between levels of processing and, interactions between sensory and cognitive processes influencing pitch representation.

## Acknowledgments

Research supported by NIH 5R01DC008549-06 (A.K.).

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# Dysarthric speech characteristics in Autosomal Recessive Spastic Ataxic of Charlevoix Saguenay (ARSACS): A Sibling Study

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## Abstract

**Background & Purpose:** Autosomal Recessive Spastic Ataxic of Charlevoix Saguenay (ARSACS) is a rare hereditary neurodegenerative disorder. The worldwide incidence of this disorder is unknown. Cardinal features of ARSACS include spasticity of the muscles, ataxia, and peripheral neuropathy. Dysarthria is often reported as the main clinical feature in ARSACS specifically during the first two decades of life. A systematic review by Xiromerisiou et al. (2020) on SACS mutation revealed a large portion of sibling studies. Globally, intra-familial phenotypic variations have been noted in these sibling studies. Siblings primarily differed based on the age of onset of the symptoms and severity. Expanding upon existing literature, here we have reported the dysarthric speech characteristics in two siblings with a clinical diagnosis of ARSACS.

**Method:** We present a case report where we have highlighted the phenotypic differences in symptom, severity and dysarthric speech characteristics between the siblings.

**Results:** Both siblings presented with mixed dysarthria, the older sibling had prominent spastic features while the younger sibling presented with ataxic features.

**Conclusion:** Overall, speech characteristics and subsystems predominantly involved indicated spastic-ataxic dysarthria type in both siblings. Through this case report, we have highlighted the detailed description of the speech characteristics in ARSACS.

**Keywords:** Autosomal Recessive Spastic Ataxic of Charlevoix Saguenay, Siblings, Dysarthric speech characteristics.

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## Introduction

Autosomal Recessive Spastic Ataxic of Charlevoix Saguenay (ARSACS) is a hereditary neurodegenerative disorder of early onset spasticity and gait ataxia first reported in the Quebec region

of Canada (Van Damme et al., 2009). It is reported to be caused by the mutation of the SACS gene localized on chromosome 13q12 (Engert et al., 2000; Richter et al., 1999). The cardinal features include spasticity of the muscles, balance and

coordination problems (ataxia) along with reduced sensation, and weakness in the arms and legs (peripheral neuropathy, Hack & Rutten, 2019). Worldwide incidence of the disease is unknown and is most likely underdiagnosed due to the occurrence of atypical clinical phenotypes (Baets et al., 2010). In the past two decades, reports have been published outside the Canadian region with marked clinical heterogeneity. (Agarwal et al., 2017; Breckpot et al., 2008; Criscuolo et al., 2005; El Euch-Fayache et al., 2003; Gregianin et al., 2013; Krygier et al., 2017; Kuchay et al., 2019; Menon et al., 2016; Mignarri et al., 2014; Miyatake et al., 2012; Narayanan et al., 2011; Palmio et al., 2016; Filho et al., 2019; Shimazaki et al., 2005; Takiyama, 2006; Tzoulis et al., 2013; Vishwakarma et al., 2017; Vogel et al., 2018; Xiromerisiou et al., 2020). The phenotypic variations documented in ARSACS include presence of hearing loss, cognitive impairment or even absence of some of the major clinical symptoms like retinal hyper-myelination and spasticity (Agarwal et al., 2017; Breckpot et al., 2008; Criscuolo et al., 2005; Hara et al., 2005; Krygier et al., 2017; Terracciano et al., 2009). Few individuals with ARSACS also exhibit deficits in naming and verbal short term memory (Krygier et al., 2017).

Specific neuro-imaging findings such as early and progressive atrophy of the superior cerebellar vermis with cervical and thoracic spinal cord thinning have been reported (Martin et al., 2007; Pedroso et al., 2011). Pontine linear hypo intensities have also been noted (Menon et al., 2016). Nerve conduction findings have confirmed mixed demyelinating and axonal neuropathy (García et al., 2008). Ocular Coherence Tomography (OCT) findings of nerve fibre hypertrophy has been reported in 33 percent of individuals with ARSACS (Pablo

et al., 2011; Vermeer et al., 1993). Hence, diagnosis of ARSACS is based on clinical symptomatology, neuroimaging findings and presence of significant thickness of retina on OCT (Duquette et al., 2013; Narayanan et al., 2011). It is further supported by nerve conduction studies and genetic evaluation (Duquette et al., 2013; Narayanan et al., 2011).

Dysarthria is defined as a group of neurological disorders with abnormalities in the speed, strength, timing, range and accuracy of movements of the articulators. The abnormalities in the control and execution of movements is due to one or more sensorimotor disturbances which is reflected as spasticity, weakness, incoordination, involuntary movements and differences in the muscle tone (Duffy, 2019). Dysarthria is one of the main clinical features seen in ARSACS during the first two decades of life (Duquette et al., 2013). Seventy four percent of patients with ARSACS report dysarthria with onset around second decade of life (Duquette et al., 2013). Previous studies have reported presence of dysarthria (Martin et al., 2007; Palmio et al., 2015; Pedroso et al., 2011), however, only one study has described speech characteristics in detail (Vogel et al., 2018). Findings report pitch breaks, prolonged intervals between words, imprecise consonants and vowel distortions as the most predominant speech characteristics (Vogel et al., 2018).

A systematic review of all published cases with SACS mutations revealed a large portion of sibling studies (almost 39%, Xiromerisiou et al., 2020). Intra familial phenotypic variations have been noted in these sibling studies across the globe (Criscuolo et al., 2005; Krygier et al., 2017; Narayanan et al., 2011; Palmio et al., 2016; Shimazaki et al., 2005). Siblings primarily differ based on the age of onset of the symptoms and severity (Narayanan et al., 2011;

Palmio et al., 2016; Pedroso et al., 2011; Shimazaki et al., 2005). Expanding upon existing literature, here we report speech characteristics in two siblings with a clinical diagnosis of ARSACS.

### **Case report**

Two male siblings SS (23 years 1 month, Male) and SY (20 years 7 months, Male), residents of south-eastern part of India, proficient in Hindi, presented with concern of poor clarity in speech and deviant walking. Siblings born into a consanguineous marriage, belonged to a low socio-economic stratum (Dudala et al., 2013), with insignificant birth history.

While a mild developmental lag was reported by parents in both siblings, both speech and motor milestones, medical records do not report of any formal diagnosis. Parents reported symptoms such as gait disturbances and unclear speech by 5 years of age for SS and by 3 years of age for SY, with preserved ability to carry out activities of daily living independently.

Neurological and radiological evaluations for both siblings revealed normal bilateral power in both upper and lower limb, and the nerve conduction studies revealed demyelinating sensory motor polyneuropathy for both siblings. Neurological findings in both showed decreased plantar responses along with positive cerebellar signs and dysdiadochokinesis. Magnetic Resonance Imaging (MRI: T2 weighted imaging) findings were conclusive of cerebral, cerebellar vermian atrophy with horizontal hypointense stripes in pons for both siblings. On OCT both siblings had increased peripapillary retinal nerve fibre layer thickness.

Based on clinical, neurological, and radiological findings, a clinical best estimate of ARSACS was

made by a multidisciplinary team that comprised neurologists, ophthalmologists, and neuroradiologists. Parents of the siblings declined to provide samples for genetic evaluation stating personal reasons. The siblings were referred to the department of speech pathology and audiology for a detailed evaluation to explore options for intervention.

Siblings accompanied by parents, were reviewed by a team of experienced speech-language pathologists (SLPs), who administered formal and informal tests. Testing began with an interview with parents and siblings, to note concerns regarding speech and language, onset of symptoms and course of these concerns. In terms of speech, siblings self-reported unclear speech, and progressive worsening of the symptoms since onset (i.e., 5 years of age for SS and by 3 years of age for SY). Hence, a comprehensive speech-language investigation was conducted. Audiological evaluations based on pure tone audiometry revealed bilateral normal hearing in SS and bilateral mild sensorineural hearing loss in SY.

A detailed oral peripheral motor examination (OPME) was conducted, followed by administration of the Frenchay Dysarthria Assessment (FDA, Enderby, 1983). To identify and classify speech difficulties, tasks of monologue and conversation were chosen. Reading tasks were not done since siblings could not read and write. Speech samples were collected to rate patients' (i) voice based on the GRBAS scale (Hirano & McCormick, 1986) and were further analysed using PRAAT (version 4.1), and (ii) speech intelligibility using the 7-point speech intelligibility rating scale of 0 to 6 developed by Ali Yavar Jung National Institute of Speech and Hearing Disabilities (AYJNISHD, Mumbai (2003), where

a rating of 0 indicates normal speech intelligibility and 6 indicates unintelligible speech even when content is known. Finally, speech of both patients was rated on the perceptual dimensions for rating dysarthric speech (PDRDS). Further, two SLPs (primary raters) with a minimum of 4 years of experience were asked to rate speech samples on the PDRDS. A third SLP with over 20 years of clinical experience was asked to rate the speech samples for eight items that the primary raters did not agree upon. Refer to the supplemental text for details of assessment battery carried out.

## Results

### Oro-motor and speech-language evaluation

Both siblings demonstrated significant difficulties in lip and tongue function compared to the jaw and soft palate on the OPME. SS displayed brisk closure for the jaw at rest, and adequate strength and range of motion for speech and non-speech tasks was observed. Lips appeared normal, with adequate range and reduced strength. Slow and laborious movements-other than for rounding-spreading task-in both speech and non-speech tasks. At rest, tongue appeared normal, with no fasciculations. Tongue strength was observed to be adequate. Bilateral slow, effortful and restricted range of motion was seen for lateral sweeps, protrusion- retraction and elevation-depression tasks. Structurally, soft palate was observed to be normal, while palatal movement was inadequate, and perceived with hypernasal speech.

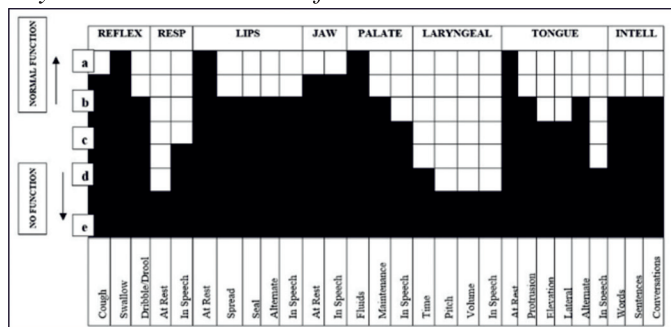
Similar findings were observed for SY too, demonstrating normal appearing jaw, adequate strength and range of motion too. Although structurally lips appeared normal at rest and lip strength adequate, lip movement for alternating tasks was slow and laborious, for both speech and non-speech activities. Tongue at rest was observed to be normal. Similar to SS, slow and limited range of

motion of the tongue was observed for similar tasks. Though, soft palate was normal in appearance at rest, movements were inadequate and hypernasality was perceived in speech. No swallowing related complaints were reported by both siblings.

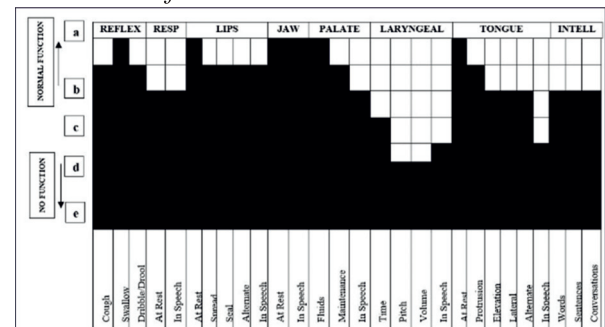
On the FDA the older sibling SS (see Figure 1a), showed predominant difficulties in laryngeal functions followed by the tongue, lips, respiratory and palatal functions. Functions affected were lack of control of pitch and volume, poor phonation and intonation, reduced phonation time, reduced tongue movements in speech and reduced ability to produce lateral movements and elevation of the tongue. Lips were observed to be normal at rest position. Mild continuous hypernasality was perceived in speech. In SY too (See Figure 1b), laryngeal functions were most affected followed by tongue, palate and lip functions. Respiratory function was better preserved. Functions affected were lack of control of pitch and volume in speech, poor phonation and intonation, reduced elevation, alternating and lateral movements of tongue. Mild and constant hypernasality was perceived in speech. Intelligibility was rated as mildly affected for both the siblings based on the FDA. The SLPs were familiar with context of the words, phrases, and sentences.

Perceptual evaluation of voice on the GRBAS indicated score of G2R2B0A1S3 (moderate deficits) for SS and G0R0B0A1S0 (mild deficits) for SY. Results of an objective analysis of voice on PRAAT version 4.1 indicated voice perturbations parameters such as jitter, shimmer, harmonics to noise ratio (HNR). The number of voice breaks and the degree was more affected in SS than SY (See Table 1). Finally, based on the AYJNISHD intelligibility rating scale, a score of 5 (i.e., can understand with effort if context is known) and 3 (i.e., can understand with concentration and effort, especially by a sympathetic listener) was obtained by SS and SY respectively.

**Figure 1a:** Results of Frenchay Dysarthria Assessment for SS



**Figure 1b:** Results of Frenchay Dysarthria Assessment for SY



**Table 1:** Results of objective analysis of voice parameters using PRAAT

Parameters	SS	SY	Normative*
Mean Pitch (Hz)	164.16	138.56	111.96-176.73
No. of Voice breaks	20	8	0
Degree of voice breaks (%)	41.79	11.87	0
Jitter (%)	3.5	2.7	0.27-1.64
Shimmer	20.15	18.75	2.09-5.00 (%)
Mean HNR (dB)	2.3	3.84	0.10-0.55

\*Normative values reported from Hema et al., (2009).

The authors (RR, ZE, SSM), who were cognizant to the diagnosis, rated the speech samples on PDRDS, independently. The difference in rating was sorted with detailed discussion and consensus rating of 2/3 votes. Most poorly rated dimensions on the PDRDS for SS included pitch breaks, monoloudness, hypernasality, strain strangled voice, slow rate, prolonged phonemes, reduced stress, and irregular Alternate Motion Rates (AMRs). These features suggested the predominant involvement of phonatory-prosodic-articulatory-respiratory-resonatory subsystems. In the younger sibling (SY) most poorly rated items included presence of monoloudness, hypernasality, slow rate, irregular articulatory breakdown, irregular AMRs and, excess

and equal stress. These features suggested most predominant involvement of the prosodic-articulatory-respiratory-resonatory subsystems.

Based on all available information a diagnosis of moderate mixed spastic-ataxic (SA, predominantly spastic) dysarthria and mild mixed SA (predominantly ataxia) dysarthria was made for SS and SY, respectively. In order to supplement our findings, speech samples, that included monologue, phonation, sequential motion rate (SMR) and alternate motion rate (AMR), were additionally blind-rated by two SLPs (primary raters) with equal experience of 4 years. A senior SLP’s opinion was sought for no consensus among

the primary raters. The primary raters had to rate these speech samples on the PDRDS. Primary raters agreed upon severity level for both SS (moderate) and SY (mild), disagreement was faced on the type of dysarthria (i.e., mixed dysarthria) for SS alone. The disagreement on the type of diagnosis (ataxia vs. mixed) was arrived at by the senior SLP as mild mixed dysarthria for SY.

Informal assessments for cognitive-linguistic skills were carried out on the siblings, and both demonstrated functionally adequate skills. The siblings demonstrated good comprehension to complex three-step commands, problem-solving skills, appreciation of humour, narration of past events, opine about topics they were familiar with. They demonstrated good occupational- functional skills, e.g., aware of basic monetary transactions, balance calculations and bill printing. SS was reported to be more active in the family occupation than SY.

## **Discussion**

This is a case report of young adult siblings, hailing from the South-East India, presenting with the condition of ARSACS, a rare and slowly progressive neurodegenerative disorder. Through this case report we highlight phenotypic differences in symptom, severity and type of speech characteristics between the siblings. Although, both siblings presented with mixed (spastic-ataxic) dysarthria, the older sibling (SS) demonstrated prominent spastic features, whereas, the younger (SY) presented with ataxic features.

During the first two decades of life, major manifestations of ARSACS are reported as early onset ataxia, dysarthria, nystagmus, spasticity of the legs, bilateral Babinski reflex, and hyperreflexia, which later proceeds to peripheral neuropathy. Pablo et al. (2011) studied the OCT images of few individuals with ARSACS and noted the increased

demarcation of the retinal nerves seen as hypermyelination of fibres as a prominent feature (Pablo et al., 2011). In the siblings reported here, there were similar symptoms of ataxia, dysarthria, spasticity with the onset being in the early decades of life. However, symptoms of nystagmus, hyperreflexia, and bilateral Babinski reflex were not observed. we hypothesize that these symptoms may appear later in life, attributed to the progressive nature of ARSACS. An OCT finding of retinal hypermyelination was identified in the second decade of life. The onset and nature of OCT findings are similar to the findings reported in literature.

Two cardinal functions reported to be affected in ARSACS are swallowing and speech (Vogel et al., 2018). Although, dysphagia is only reported by Vogel et al. (2018), siblings in our study did not complain of swallowing difficulties. Though the evaluations carried out did not establish the presence oral dysphagia, considering the present oro-motor deficits in the siblings, we recognize that siblings in this study might eventually present with dysphagia. The absence of dysphagia symptoms could be attributed to the present age of the siblings. They were younger when compared to participants (onset age 32.7 years) in the study by Vogel et al. (2018). Findings on oro-motor evaluations are suggestive of coordination deficits for alternating tasks in both siblings. Speech evaluations on FDA and PDRDS indicated significant deficits in respiratory-phonatory-prosodic-articulatory subsystems in SS and prosodic-articulatory subsystems in SY. Although, monoloudness was present for both the siblings, respiratory subsystem was better preserved for SY than SS. While resonatory subsystem was affected in both the siblings, SS had greater amount of hypernasality than SY in speech. These respiratory-resonatory subsystem involvement could have impacted the speech intelligibility as evident on the AYJNISHD speech intelligibility rating scale.

Speech characteristics such as pitch breaks, equal and excess stress, imprecise consonant clustering into the phonatory, prosodic, articulatory systems were in line with those reported by Vogel et al. (2018). However, hypernasality and monoloudness were two speech characteristics that were unique to our siblings. The probable reduction in range and force of velopharyngeal movements, along with insufficient excursion of the respiratory muscles resulted in a resonatory-respiratory incompetence in the siblings.

In order to reliably comment on the type of dysarthria in the siblings, speech samples were rated by speech language pathologists. Although consensus on type and severity of dysarthria was arrived upon for SS (moderate mixed dysarthria), there was disagreement about the type of dysarthria for SY. This could be due to severity of the dysarthria in SY (mild). It is possible that categorizing mild deficits is challenging than the severe deficits. Finally, findings based on perceptual analysis of voice was supported by objective measures (PRAAT). Increased jitter and shimmer, and reduced HNR seen in both siblings, have been typically reported in dysarthric pathological voices (Carillo & Ortiz, 2007). Overall, speech characteristics and subsystems predominantly involved indicated spastic-ataxic dysarthria.

Although diagnosis of ARSACS in the siblings was made based on well documented history, expert clinical opinion and radiological evaluations, we recognize that a genetic confirmation would have strengthened the diagnosis. The family had not sought intervention since the onset of symptoms (since childhood). Due to financial and logistical issues the family refused to seek long term intervention from the research team. However, intervention strategies suggested to the family focused on (1) oral isotonic and isometric exercises

to increase the strength and range of motion of the articulators, (2) enhancing speech intelligibility along with environmental modifications and (3) understanding the principles of motor learning (i.e., importance of drill and feedback).

## Conclusion

This case report highlights the dysarthric speech characteristics in two siblings who have been diagnosed with ARSACS. Subsystem analysis and perceptual speech characteristics indicated spastic-ataxic type of dysarthria in both the siblings. This study adds to the existing, albeit limited literature on ARSACS with a focus on in-depth characterization of speech deficits in two siblings. Role of speech-language pathologists is crucial in evaluating and intervening several medical genetic conditions that involve speech language difficulties.

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\* \* \*

# Dysarthric speech characteristics in Autosomal Recessive Spastic Ataxic of Charlevoix Saguenay (ARSACS): A Sibling Study

## Supplement Material

Details of Tests administered on siblings:

- a) **Oral Peripheral Motor Examination (OPME)** is carried out to assess the strength, range, steadiness, speed, tone, and accuracy of the articulators involved in the function of speech. The articulators assessed are the jaw, lips, tongue, hard and soft palate. These articulators are assessed both at rest and speech tasks. Assessing strength provides an insight about the muscle contraction and muscle reserve strength (i.e., strength required for muscle contraction without fatigue). Muscle weakness has an influence on all the components related to speech production, i.e., respiration, phonation, articulation, resonance, and prosody. The assessment of range of motion of the articulators reveals the extent to which the articulators can move with precision for repetitive movements. This information is crucial, as decreased range has a major influence on prosody. Steadiness of articulators is examined as absence of involuntary movements in the articulators. Breakdown in steadiness is seen to affect accuracy of speech and, also prosody. Speed of articulators measures the rapid, discrete movements, when affected adversely influences the syllable rate production, loudness, and pitch variability. Muscle tone is indicated by excessive or reduced muscle bulk. Both excessive and reduced muscle bulk affects overall speech production. Accuracy includes the ability to produce sounds precisely and intelligibly.
- b) **Frenchay Dysarthria Assessment (FDA; Enderby, 1980)** is a subjective assessment tool. This assessment assists in categorically diagnosing dysarthria based on observations and grading of speech and non-speech tasks. The test has 11 subsets: Reflex, Respiration, Lips, Jaw, Palate, Laryngeal, Tongue, Intelligibility, Rate, Sensation, and Associated factors. A 9-point rating scale is used to score the patients response for each subtest. Results are then charted on a bar graph with the 9-point scale on the perpendicular axis, and the eight tests and corresponding subtest on the horizontal axis.
- c) **Perceptual Dimensions for Rating Dysarthric Speech (PDRDS; Darley et al., 1969)** is a perceptual rating scale. This rating scale entitles rating of 38 distinctive features of dysarthric speech across dimensions that are related to pitch, loudness, voice, resonance, respiration, prosody, and articulation. The rating is based on a 7-point Likert scale, where 0=least deviant and 7= most deviant.
- d) **GRBAS (Hirano & McCormick, 1986)** is a subjective assessment tool that is used to assess voice parameters. The voice parameters assessed are Grade, Roughness, Breathiness, Asthenia, and Strain. The parameters are arranged on an ordinal scale across severity, with values ranging from 0 to 3: wherein, 0 = normal voice or absence of disorder; 1 = mild disorder or in case of doubt the existence of alterations; 2 = moderate disorder; 3 = severe disorder.

- e) **PRAAT** is a free speech software that assist in analysing, synthesising and manipulating speech samples. For this study, PRAAT was used for acoustic analysis of the sibling's speech. Acoustic parameters like jitter, shimmer, harmonics to noise ratio (HNR) and number and degree of voice breaks were analysed.
- e) **AYJNIHH speech intelligibility rating scale** is a perceptual rating scale devised by the Speech-Language Pathology Department of AYJNIHH in 1984. This is a 7-point rating scale, where 0 - Normal and 6 - Cannot understand at all even when context is unknown.

\* \* \*

# APHASIA AND OTHER ACQUIRED NEUROGENIC LANGUAGE DISORDERS

A Guide for Clinical Excellence (2<sup>nd</sup> edition)

- Brooke Hallowell, Ph.D., CCC-SLP

ISBN-10 1635501598; ISBN-13 978-1635501599; ISBN 9781597569552 (e-book)

Publisher: Plural Publishing Inc;

Publication date: 28<sup>th</sup> Feb. 2022

This book is available on Amazon for Rs.8,096/-

Reviewed by Ms. Prajna Kodgi

Dr. Brooke Hallowell brings over thirty years of her clinical, teaching, research, and advocacy expertise into this book, which makes this book a fantastic contribution to the current literature on neurogenic communication disorders. The structure of the book is divided into 8 sections across thirty three chapters i.e., Section I: Welcome and Introduction; Section II: Foundations for considering acquired neurogenic language disorders; Section III: Features, symptoms, and syndromes in the major categories of cognitive-linguistic disorders; Section IV: Delivering excellent services; Section V: Strategic and meaningful assessment; Section VI: Theories and best practices in intervention; Section VII: General approaches to treatment; and Section VIII: Specific treatment approaches. This textbook includes a well-framed index, a thoroughly charted glossary, and exhaustive references. Each chapter begins with a clear set of objectives, crucial terminologies are in bold in the content of the chapter and the chapter closes with a learning and reflection activity to assess the learning outcomes, offering valuable feedback to readers.

**Section I:** The introduction to the book sets the tone for a fulfilling journey through the marvellous world of research and clinical practice of acquired

neurogenic communication disorders, enticing the reader with a personal touch. The author elaborates on basic concepts, interdisciplinary approaches, and career development and choices. This is followed by guidelines to be an excellent clinician. Significant pointers such as patient interview and report-writing, managing patient care-giver and other professionals are highlighted, as well.

**Section II:** The foundation for adult language disorders is well-laid by introducing various acquired neurogenic language disorders and challenges faced. Multiple frameworks are provided to understand the concept of aphasia. Compendiously, the WHO ICF framework (World Health Organization International Classification of Functioning, Disability and Health) is explained with emphasis on its relevance to ethics and human rights, people with neurogenic language disorder, and intervention and research. Aetiologies, symptoms, characteristics, and associated conditions of acquired neurogenic communication disorders are covered. Neurophysiology and neuropathological aspects are well represented for a Speech Language Pathologist (SLP) concerned with aphasiology. Types of neuroimaging and neurodiagnostic instrumentation are simplified. Although not pathological, 'Aging as normal changes in the brain'

is well elucidated in this section, as it may hamper cognitive linguistic abilities and effective communication. To understand the diverse construct, the reader is provided with appropriate general guidelines and theories that are important for SLPs to understand.

**Section III:** This section highlights hallmark characteristics and features, symptoms of aphasia, and major categories of acquired language disorders such as Traumatic Brain Injury, Right Hemisphere Damage, Primary Progressive Aphasia, Dementia, and other neurodegenerative conditions with associated cognitive linguistic challenges.

**Section IV:** Section IV emphasizes the deliverance of excellent services across types of settings and engaging proactively in advocacy, legal and ethical concerns. Despite a limited application to the Indian context, Chapter 14 in this section aids the reader in understanding the system of insurance, reimbursement of speech therapy sessions, payments to SLPs, and cost control systems in the United States of America. This may prove useful to Indian students who desire to pursue higher education or employment overseas and also sensitize them to insurance affairs and the reimbursements. Emphasis is given to legal and ethical concerns by raising awareness and educating professionals, encouraging referrals, promoting community-based practices, promoting access to services, support and advocate the rights of persons with neurogenic communication disorders, and their support systems. The author presents the reader with global perspectives on clinical aphasiology, presenting insights to international trends.

**Section V:** This section addresses the importance of implementing strategic assessments by employing best practices. Here, the focus is given

to the person-with-disability and life participation goals, mindful of their strength and multiple communicative perspectives in daily living. The detailed assessment, with illustrious case histories offers sensitivity to the linguistic and cultural differences. The chapter revisits the need for a process analysis approach to assessment, the use of dynamic non-standardized with a standardized assessment, and the need to integrate criterion and referenced measures, which are well expressed. Brief well-explained psychometric properties to be assessed in the assessment process are portrayed. A clearly laid out table describing the cognitive and linguistic functions, assessment items, and potential confounding variables is presented. In addition to this, screening interview questions and tasks are summarized. A well-described problem-solving approach is addressed, for persons with neurologic language disorder exhibiting associated conditions requiring differential diagnosis. Dr. Hallowell presents an extensive reference to assessment resources such as scales, tests, and screening tools with details on the target population, domains for assessment, and time taken are included which can act as a quick guide for clinicians. Interesting details on discourse analysis and documentation of prognosis which are vital in assessments are available. Not only are references to programs for transcribing and analysing discourse put forth, examples of categories of discourse analysis along with interpretation are also listed. Documentation of assessment reports with a note on prognostic indicators is incorporated. A compilation of common abbreviations used in rehabilitation documentation is constructed in this section as well.

**Section VI:** The best practices and theories of intervention are addressed by laying the foundation with clear guidelines for implementing

functional and practical approaches that value practice-based evidence. The author's description on the need for integrating evidence-based practice with practice-based evidence in one's professional activity is eye-catching. The goal of intervention and the theories behind the intervention methods to improve language and cognition are similarly well-depicted.

**Section VII:** This section begins with approaches to a wide range of cognitive communicative disorders such as people with TBI, PPA, dementia, and stroke survivors. This section on treatment captures the reader's attention as the information on life participation is beautifully elaborated. It includes supported communication, total communication, partner and caregiver training, reciprocal scaffolding, workplace immersion programs, aphasia mentoring programs, toastmaster programs, humour as therapy, online games, AAC, apps, aids, and software availability, other socially-focused programs, stimulation facilitation approach, and residential aphasia programs. Summary tables on group therapy activity ideas are available. Multiple roles of SLPs in facilitating communication among people with PPA and dementia are well-explained. Caregiver coaching, training, and support, use of memory books and wallets were mentioned. Approaches such as Montessori were also provided with supplementary tables, a sample of the script for a Spaced Retrieval Training, strategies of FOCUSED program, and breakfast club activities were elaborated. The author highlights being an effective counsellor and life coach by promoting a positive outlook impacting one's recovery. Website links to support people with neurogenic communicative disorders are also mentioned. Details on approaches that are complementary to and integrative with traditional types of intervention such

as mind-body practice, the role of religion and spirituality, herbal, etc are included.

**Section VIII:** The final section is dedicated to the specific approaches for promoting communication. The essence of this section is that the approaches are explained with principles, steps of implementation, and status in evidence-based practice. The reader is provided with details on treatment steps that are easy to comprehend and can be applied clinically. Emphasis is given to a cyclic approach to adult learning i.e., when one aspect is mastered, it complements other aspects as well. Dr. Hallowell has presented these approaches under following heads.

1. *To improve compensatory communication strategies:* Promoting Aphasics' Communicative Effectiveness (PACE), Communicative Drawing Program (CDP), Back to the Drawing Board (BDB), and Visual Action Therapy (VAT).
2. *To enhance expressive language:* Constraint Induced Language Therapy (CILT), Script Training, Melodic Intonation Therapy (MIT), Voluntary Control of Involuntary Utterances (VCIU), Response Elaboration Training (RET) and Treatment of Aphasic Perseveration (TAP).
3. *To improve word finding and lexical processing:* Cueing Hierarchies for the treatment of Anomia, Semantic Feature Analysis, Phonological Component Analysis, Verb Network Strengthen Treatment (VNeST), and Verb as Core.
4. *Syntax approaches -* Treatment of Underlying Forms (TUF), Mapping Therapy, and

Sentence Production Program for Aphasia (SSPA).

5. *Reading and writing* - Copy and Recall Treatment (CART), Anagram and Copy Treatment (ACT), Problem Solving Approach, Multiple Oral Reading (MOR), and Oral Reading for Language in Aphasia (ORLA).

The book has diagrams, charts, illustrations, summary tables, lists/tables of test materials, worksheets, samples of case histories, and case examples to promote learning even in the youngest student. A highlight of the book is availability of the supplemental materials with various online tools such as power points, learning exercises, videos of links, and test banks for which registration is required. Different pedagogic methods are adapted to support self-learning and classroom learning which helps to build concepts in analysis and application.

In line with the book's title, the author has been successful in outlining a clear road to excellence for a clinician with regard to clinical practice efficacy in

acquired neurogenic language disorders. This book is a must-read for academicians who teach the program as it incorporates major recent advances throughout the text and for students who aspire to be true clinicians as they can imbibe the dos and don'ts of clinical practice following true professionalism and ethics. This guide will ease the transfer of theoretical perspective to clinical practice. The book gives thoughtful attention to details of multicultural perspectives, and cultural factors in clinical practice and a global perspective that promotes equity, diversity, and inclusion. The content on approaches to treatment is brief with details, and treatment steps are easy to comprehend and can be applied clinically. The book will serve as the SLP's one-stop shop for everything from the fundamentals to the available research. I recommend that every library own this book as it is -what I call-"a magical guide", that directs newbies and professionals alike to succeed in their field. I thank the author for the meticulous effort, in-depth research, and passionate practice she put into compiling this vast book of wisdom.

\* \* \*



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 B++ accreditation by NAAC



## Fellowship Curriculum



The curriculum includes orientation on anatomy and physiology of Head and Neck cancer

Hands on experience for Speech, Swallowing assessment and treatment of individuals with Head and Neck cancer



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## FELLOWSHIP ON SPEECH AND SWALLOWING REHABILITATION AFTER HEAD AND NECK CANCER TREATMENT

7th Batch

**Date of Commencement: 03-01-2024**

**Course Duration**

5 months

**Course Instructor**

**Dr. B S Premalatha**

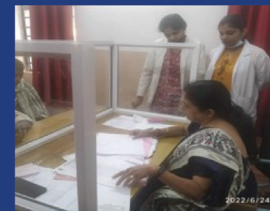
with more than 35 years of experience in the management of speech and swallowing of Head and Neck cancer patients

**Eligibility**

Completed BSLPA/  
 BASLP/MASLP/MSc. SLP

**Maximum Intake**

6 students



**Conducted by Department of Speech-Language Studies**

### ABOUT

- The fellowship is for 5 months and it aims to provide clinical training in speech and swallowing rehabilitation for Head and Neck cancer patients
- The programme includes one month of postings in Kidwai Memorial Institute of Oncology, Bangalore and in Narayana Hrudayalaya Hospital, Bangalore
- Three months of posting at the Institute will involve coursework that is taught by a team including surgeons, nurses, speech & swallow therapist, radiologist, nutritionist, dietician, physiotherapist and social worker

### FACILITIES

- Clinical postings at the well equipped dysphagia unit at Dr. SRCISH
- Demonstration of instruments such as Vitalstim device, Voice prosthesis, Tracheostomy tubes etc



### HIGHLIGHTS

Observation of head and neck cancer surgeries, OPD consultation along with Head and Neck surgeons

Theoretical teaching and rehabilitation of Head and Neck cancer patients

Hands on speech and swallowing assessment and treatment in Head and Neck cancer patients

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## DR. S.R. CHANDRASEKHAR INSTITUTE OF SPEECH AND HEARING, BANGALORE

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# FELLOWSHIP IN CLINICAL AUDIOLOGY

Dr S R Chandrasekhar Institute of Speech and Hearing is pleased to offer a 4 month on site Clinical Audiology Fellowship program. This fellowship program offers a unique opportunity by enabling candidates gain significant experience quickly in a short span. Candidates with avid interest in Audiology are welcome to apply.

### HOW CAN A FELLOWSHIP IN CLINICAL AUDIOLOGY HELP YOU?

As the field of Audiology is vast, there is a constant need to sharpen the skills and spruce up our knowledge on a daily basis and with the pandemic badly striking the clinical exposure, we intend to bridge the gap between student life and professional life of an Audiologist through this fellowship.

This fellowship can set you a part and increase your employability.

Learning from one of the leading institutes of Speech and Hearing in India and interacting with experts through our comprehensive fellowship program will enable you to efficiently translate current science to everyday clinical practice.

On completing this fellowship, you will demonstrate competency in several aspects of Clinical Audiology.



### WHAT WILL YOU LEARN?



The program is designed to offer an intensive clinical exposure at a stretch of four months in Clinical Audiology. It comprises of direct hands-on experience under supervision in the following areas:

Behavioral Tests Immittance Otoacoustic Emissions

Auditory Evoked Potentials Hearing Aid trial, fitting and observation of fine tuning Vestibular Assessment Neonatal Hearing Screening in hospital setup Pre and post Cochlear Implant Assessments Exposure to special population: ANSD, CAPD, Disability Certification Observation of AVT and observation of Cochlear Implant MAPPING.

### WHY CHOOSE DR.S.R.CHANDRASEKHAR INSTITUTE OF SPEECH AND HEARING?

The Institute has been a pioneer in the field of Speech and Hearing with its rich clinical and academic background spanning over 45 years. The institute takes pride in offering clinical services for a wide range of patients and broad exposure to students. The Department of Hearing Studies is well equipped with variety of instruments and facilities to diagnose and treat Hearing and Balance Disorders. Our Audiology teachers are highly qualified with diverse experience and has distinguished experts in the team.

### WHO CAN JOIN?

Anyone with a minimum qualification of Bachelors in Audiology and Speech Language Pathology (BASLP) or higher qualification in the field of Speech and Hearing.

Getting back to work after a break / sabbatical can sometimes be unnerving / challenging. By enrolling in this fellowship you cannot only have a thorough refresher in audiology but also bag an additional qualification.



### COMPLETION CRITERIA

Upon successful completion of the fellowship the candidate will be awarded a course completion certificate  
The candidate will be evaluated based on: end of course evaluation, attendance and performance at clinics

**AVAILABLE SEATS : 5**

**HOW TO APPLY?**

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**VOICE DISORDERS ◆ CLEFT LIP AND PALATE**  
**MISARTICULATION ◆ DIFFICULTY IN SWALLOWING**  
**AUTISM ◆ STUTTERING ◆ BALANCE ISSUES**



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### **Guidelines for authors:**

Manuscripts should be submitted in word file-.doc/.docx. and follow the APA 7 format.

**Title page** should be separate with authors names, affiliations, and corresponding author details should be included.

**Abstracts:** Structured abstract with Background and Purpose, Methods, Results, and Conclusion. Abstract should be less than 300 words excluding references. Sufficient details in the abstract to be provided with respect to participants, testing, and procedure.

**Keywords:** Five to seven key words should be listed end of the abstract.

Short running title of less than 50 characters should be included.

### **Main manuscript**

Introduction should lead to the need of the study and aims. Methods section must include study design, details of participants, materials used, rationale, procedure, and statistical analysis. Titles for figures and text must be clear and self-explanatory, providing information as a stand-alone structure. Stand-alone, high-quality figures and tables should be included in results section. Discussion section should provide understanding of results with support from literature. The manuscript should end with conclusion that brings out implication of the study.

All manuscripts should include acknowledgements, conflict of interest statement, ethical approval statement, participant consent statement, and funding statement at the end of the article.

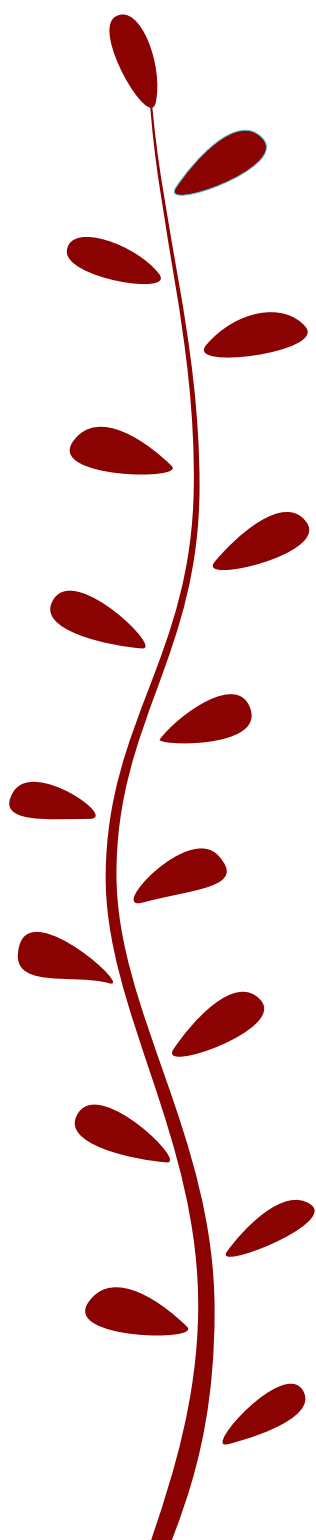
Resolution for figures JPEG/PNG should be a minimum of 300 DPI. It is preferred that all content be original. If figures are taken from another source, the author(s) is/are responsible for taking the permission/paying from the authors of the figure.

Ethical approval of the study and informed consent should be mentioned at the time of submission. Figures that include identifiable information about participants need to have an informed consent that is provided by the author.

Spacing- Double spaced with continuous line numbers. Single spaces after the period. Page numbers should be provided.

Articles are peer reviewed. Authors are encouraged to suggest reviewers, though the final decision is made by the editorial board.

All effort will be made to review the articles within 4 weeks.



# BANGALORE SPEECH AND HEARING TRUST JOURNAL OF HEARING LANGUAGE AND SPEECH.

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