Frequency Following Response Workshop

22nd & 23rd May 2014 (London, UK)

Thursday 22nd May 2014
(9am – 5pm)

9.00: Registration

9.30: Welcome / Opening Remarks

Session 1 - Origins and interpretation of the FFR

9.40: **FFR: Where it does (not) come from and what it does (not) show**
Hedwig Gockel
MRC - Cognition and Brain Sciences Unit, Cambridge, UK

10.30: **Cochlear influences on the timing of the speech-ABR**
Helen Nuttall
MRC Institute of Hearing Research, Nottingham, UK & University College London, UK

11.20: Coffee break

11.40: **Temporal coding in single cells and its reflection in mass potentials**
Philip Joris
University of Leuven, Belgium

12.30: **Round Table: Does the FFR tell us anything about brainstem processing, or is it just a simple reflection of peripheral encoding?**

13.00: Lunch

Session 2 – New Techniques

14.00: Unweaving the Rainbow: Sensitivity to Stimulus Phase and Polarity in the Human Frequency Following Response
Steve Aiken
Dalhousie University, Canada

14.50: Extracting the cochlear microphonic from the FFR
Paul Deltenre
Université Libre de Bruxelles, Belgium

15.40: **Poster session**

Friday 23rd May 2014
(9.40am – 4.30pm)

Session 3 – Hot topics

9.40: **The FFR as a tool to evaluate TFS decline in ageing and as a measure of "hidden" hearing loss**
Garreth Prendergast
The University of Manchester, UK

10.30: **Assessment of cochlear neuropathy using far-field potentials: ABR vs. EFR**
Luke Shaheen
Harvard-MIT Division of Health Science and Technology, USA

11.20: Coffee break & poster session

12.10: **From single-unit to population responses: contributions to auditory-brainstem and frequency-following response generators**
Sarah Verhulst
Oldenburg University, Germany

13.00: Lunch

14.00: **Frequency following responses measured in cochlear implant users**
Michael Hofmann
University of Leuven, Belgium

14.50: **Language experience shapes representation of pitch relevant neural activity in the human brainstem**
Ananthanarayan Ravi Krishnan
Purdue University, USA

15.40: **Round Table: How should the FFR be quantified? What are the biases inherent in each measure?**

16.10: Closing remarks

Poster abstracts

Evidence for binaural interaction component at the brainstem level using speech stimuli

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There is ample evidence showing that integrating information that arrives from both ears is important for understanding speech in noisy situations, crucial for localizing the source of the sound and assists in ease of listening. There is also electrophysiological data suggesting that this integration, also known as binaural interaction, occurs along the ascending auditory system from the brainstem to the auditory cortex. Specifically, it has been documented that a binaural interaction component (BIC) can be derived by subtracting auditory evoked responses to binaural stimulation from the sum of the responses of monaural stimulation. BIC has been extensively studied at the brainstem level for click stimuli and tonal stimuli but not for speech stimuli. Recording responses to speech stimuli at the brainstem level also provides us with a unique opportunity to follow the neural signatures of the acoustic properties of the input signal (e.g., pitch tracking, harmonics, onset timing, formant timing etc). Thus, the purpose of the present study was to document BIC for speech stimuli at the brainstem level, as it may provide us with the neural signatures of specific speech elements at the early stages of binaural integration. Twelve normal hearing young adults aged 22-28 years of age participated in the present study. Auditory brainstem responses (ABRs) were recorded to the naturally spoken syllable /da/ in three listening conditions: left monaural, right monaural and binaural. BIC was derived by subtracting the ABR response to the binaural stimulation from the sum of the responses to the monaural stimulation. BIC was documented in the two components of the ABR response to speech stimulus: (1) the onset response which arises from the broadband stop burst /d/, and (2) the frequency following response (FFR) which arises from the fundamental frequency and harmonics of the consonant-vowel formant transition and the vowel /a/. BIC manifested itself by a reduction of the binaural response compared to the sum of the monaural responses. These results provide, to our knowledge, first time electrophysiological evidence for the binaural interaction of speech stimuli at the brainstem level. These results have important implications regarding the use of BIC as a potential tool for assessing binaural processing in clinical populations including those that have difficulties understanding speech in noisy environments and hearing impaired with bimodal versus bilateral auditory stimulation.

Poster 1

The effects of high-frequency noise on the FFR to low-frequency musical dyads and on the perception of consonance

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Pleasantness ratings for different two note chords (dyads) correspond closely to the neural representation of the harmonicity of those dyads reflected in the FFR. Individuals with a greater preference for consonance have a greater distinction between the representation of harmonicity in consonant and dissonant dyads in the FFR generated by phase locking to individual harmonics. When two notes of a consonant dyad are presented to the same ear, dyads are perceived as being more consonant than when the two notes are presented to separate ears. When two notes are presented to the same ear, interactions between the harmonics of the two notes on the basilar membrane result in additional frequency components being present in the FFR. These components enhance the harmonicity of the FFR, suggesting that this could be the physiological mechanism for the increased perception of consonance in the diotic condition. Overall, there is evidence that consonance preference depends in part on the sub-cortical neural temporal representation of harmonics and their cochlear interactions (Bones et al, in press, 2014). In the current study we test the hypothesis that the FFR to low-frequency dyads reflects the neural response from regions of the cochlea basal to the region tuned to the harmonics (as suggested by other authors e.g. Dau, JASA, 2003) by recording the FFR to low-frequency dyads in the presence of high-frequency noise. In addition, if harmonic salience of phase locking in the auditory brainstem is related to the perception of consonance, degradation of the FFR caused by the high-frequency noise should also result in a decrease in consonance preference. Secondly, Gockel, Farooq, Muhammed, Plack, and Carlyon (JASA, 2012) demonstrated that distortion products measurable in the FFR were much larger than would be expected had they been generated by propagated cochlear distortion products. An alternative is that the distortion products arise from a non-linear response to harmonic interactions in neurons with characteristic frequencies in the region of, or possibly above, the frequencies of the harmonics. To test this hypothesis we compared our data to the output of a model including a non-linear cochlear filterbank, and an inner hair cell (IHC) receptor potential simulation (Sumner, Lopez-Poveda, O'Mard, and Meddis, JASA, 2002). The effect of the noise was to reduce consonance preference and to reduce the harmonic salience of the FFR by reducing the absolute amplitude of the harmonically relevant spectral peaks, suggesting a nonlinear mechanism of suppression. The harmonically relevant distortion products in the FFR could be accounted for by the output of both low and high frequency IHCs in the model. However, the effect of noise on the FFR was unaccounted for by the model.

Poster 2

A Survey of FFR Data from the Auditory Neuroscience Laboratory at Boston University

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The following is a survey of various FFR studies conducted at the Boston University Auditory Neuroscience Laboratory. FFR measures were obtained quickly using a novel approach that employs multichannel recordings and frequency-domain complex-principal component analysis.

Individual differences in FFR
FFRs were measured from 30 individuals with normal hearing thresholds (NHTs) in response to high frequency amplitude modulated tones plus off-frequency masking noise as both sound level and modulation depth were systematically varied. In the same cohort, both monaural and binaural measures of temporal acuity were obtained along with characterization of cochlear function using otoacoustic emissions and psychophysical tuning curves. Results showed that individual differences in subcortical neural synchrony at shallow modulation depths and high sound levels, and not cochlear measures, accounted for the large individual differences in perceptual measures of temporal acuity.

ABR and ITD discrimination
Click- ABRs were measured in quiet at click levels of 50-90 dB pSPL (10 dB steps) and in broadband noise with varying noise levels from 42 – 82 dB SPL (10 dB steps, click level=80 dB pSPL) in NHT listeners. In the same subjects, we measured envelope ITD just noticeable differences (JND) (re: zero) of a narrowband signal with notched-noise maskers. Results show a significant correlation between the rate of change in the wave-V latency and envelope ITD JND.

FFR and binaural interactions
FFRs to 100Hz high-pass click trains were recorded from a group of eleven subjects with normal hearing thresholds. The 100 Hz PLVs computed from the FFR in the binaural condition roughly equaled the sum of the monaural responses. We also recorded FFRs to a 20-Hz binaural beat stimulus consisting of complex tones with different pitches to two ears. The PLV of the reconstructed source signal showed a peak at the 20Hz binaural beat frequency. The amplitude of this response varied greatly across subjects.

FFR and blast exposure
FFRs to 100-Hz modulated 4-kHz transposed tones at four different modulation depths (100, 63, 40, 25%) were collected from a group of blast-exposed veterans diagnosed with mild traumatic brain injury. Average hearing thresholds of the veterans were ~20 dB HL. PLVs of both the veterans and a cohort of healthy controls showed a great degree of variability. Furthermore, despite frequent exposure to high intensity sounds, PLVs of the veterans were indistinguishable from those of healthy control subjects.

Poster 3

<<Axelle's abstract>>

Poster 4

Auditory regularity encoding in Autism Spectrum Disorders: brainstem responses to repeated amplitude-modulated sounds

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Children with Autism Spectrum Disorders (ASDs) often show atypical sensitivity to auditory stimulation and exhibit difficulties in the processing of auditory information.

Regularity encoding is a basic property of the auditory system and any disruption in the low level encoding of acoustic regularities might underlie processing deficits, as observed in ASD. In this study, we aimed at characterizing how repetitive stimulus presentations modulate the frequency following responses (FFR) of the auditory brainstem in children diagnosed with ASD. To test this, we used a roving standard paradigm consisting of 10 pure tones, each with different carrier frequencies and a common amplitude modulation of 380 Hz. Each tone was repeated 8, 10 or 12 times with a constant stimulus onset asynchrony (333ms). Electroencephalographic recordings were obtained from 16 children diagnosed with ASD and 16 matched typically developing (TD) children (age range: 6.5-12 years). We examined the repetition effects on brainstem FFRs to the AM frequency, and how these effects differed between the two groups. The patterns of FFR modulations as a function of stimulus repetition clearly differed between both groups (p=.013, RMANOVA), with ASD children showing a linear increase of FFR power with stimulus repetitions, whereas TD children's responses decreased after 4 repetitions. These results suggest that the encoding of acoustic regularities in ASD children is altered at the level of the auditory brainstem, with ASD children displaying atypically enhanced responses to simple acoustic features.

Poster 5

Sensitivity of envelope following responses to vowel polarity

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When recording frequency-following responses to vowels, responses are typically averaged to vowels presented in opposite polarities to enhance neural responses elicited by the vowel envelope (i.e., the envelope following response or EFR). However, recent studies demonstrate polarity-sensitive amplitude differences in EFRs elicited by vowel stimuli. The aim of this study was to evaluate the effect of vowel, resolvability of harmonics, and presence of the first harmonic (h1) on polarity sensitivity of EFRs. Twenty participants with normal hearing participated in the study. EFRs were elicited by resolved (first formant, F1) and unresolved (second formant and higher, F2+) harmonics of naturally produced vowels /u/, /a/, /i/. Individual but simultaneous EFRs were elicited by F1 and F2+ carriers by separating the fundamental frequency in the two regions by 8 Hz. These vowels were presented in a naturally produced, but modified sequence /susaʃi/ at 65 dB SPL. To evaluate the effect of h1 on polarity sensitivity of EFRs, EFRs were elicited by the same vowels without h1 in an identical sequence. The stimulus sequences with and without h1 in opposite polarities were presented in an interleaved manner. A repeated measures analysis of variance indicated a significant interaction between polarity, vowel and h1 on EFR response amplitudes for F1 carriers only. Post-hoc paired t-test comparisons indicated a significant effect of polarity on EFR amplitudes for /u/ F1 and a near significant trend for /i/ F1, when h1 was present. EFRs elicited by other F1 carriers with and without h1, and F2+ carriers demonstrated no significant effect of polarity. The results suggest that h1 contributes to the polarity sensitivity of EFRs elicited by low frequency F1 carriers. However, it is unlikely that this is only due to the influence of a polarity-sensitive frequency-following response to the fine structure at h1. The removal of h1 also decreased the asymmetry of the vowel envelope, especially for F1 carriers with low frequency F1. A measure called the envelope asymmetry index was computed to evaluate the relationship between envelope asymmetry and polarity-sensitive amplitude differences in EFRs. A significant positive correlation suggests that one of the causes contributing to the polarity sensitivity of vowel-elicited EFRs could be asymmetry in the stimulus envelope.

Poster 6

The frequency-following response reflects spontaneous perceptual switching in auditory streaming

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When presented with a prolonged sequence of two tones (A and B) with different frequencies (ABA-ABA-ABA-….; - indicates silence), listeners tend to report either percept of a single coherent stream (S1) and two segregated streams (S2). The S1 and S2 states alternate spontaneously in a stochastic manner. This phenomenon can be considered to reflect the inherent brain processes that explore interpretations of ambiguous auditory scene, which is often encountered in natural environments. Neural correlates of auditory streaming have been reported both in subcortical and cortical sites. However, limited information is available as to the contribution of the human brainstem to the perceptual switching. We examined the correlation between the frequency-following response (FFR) and behavioral reports of the two percepts.

In the experiments, the A and B frequencies were 315 and 400 Hz, respectively. The duration of each tone was 50 ms, including 10-ms rising and falling ramps. Normal-hearing adults participated in the experiment. An experimental session consisted of typically 200 repetitions of ABA- triplets, during which the participant was instructed to press a button corresponding to S1 or S2 percepts whenever they experienced perceptual switching. At the same time, the FFR was recorded using a vertical one channel electrode montage; Cz (active), ipsilateral earlobe (reference), and forehead (ground). The recorded FFRs corresponding to the A and B tones in individual ABA- triplets were classified according to behavioral reports (S1 or S2), and then were averaged within each perceptual status.

The averaged FFR amplitude for the second A tone in the triplet was significantly smaller in S1 than in S2. Additionally, the time course of the FFR amplitude showed somewhat systematical changes in prior to the listener's button-press response. These results suggest that brainstem-level processing is involved in the spontaneous perceptual switching, and the FFR change can be a precursor to the switching.

Poster 7

Multi-channel electrically evoked auditory brainstem responses based interaural electrode pairing method for bilateral cochlear implants

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Bilateral cochlear implants have succeeded in improving both speech perception and spatial hearing performance of CI users, albeit considerable variability across implantees. Limited success can be caused by an interaural mismatch of the place-of-stimulation that arises from electrode arrays being inserted at different depths in each cochlea. Finding matched interaural electrodes is expected to facilitate binaural functions such as binaural fusion, localization, or detection of signals in noise. A 64-channel electrically evoked auditory brainstem responses (eABR) based objective interaural electrode pairing method was proposed in our lab by determining the subcortical binaural interaction component (BIC). The BIC is derived for several interaural electrode pairs by subtracting the response from binaural stimulation from their summed monaural responses: BIC = (left alone) + (right alone) – (left and right together). The main goal of the study is to objectively identify corresponding left-right CI electrodes, with the underlying assumption that these pairs have a larger BIC than unmatched pairs. A multi-channel brainstem EEG recording is performed, where eABRs were recorded from up to 64 sites with the common reference electrode placed at the vertex (Cz) and the ground electrode at the forehead (Fpz). The stimuli for the eABR were generated and sent through the research coils to the bilaterally implanted MED-EL CI subjects via a computer controlled MED-EL research platform RIB2. In this study, the bilaterally CI subjects are stimulated at 60% dynamic range with 19.9 biphasic pulses per second. For the data analysis the first millisecond after stimulation, where a huge electric artifact from the CI is dominant, was removed by linear interpolation and an independent component analysis (ICA) was applied on the preprocessed multi-channel EEG data. A strong benefit of the signal quality could be demonstrated with the multi-channel recording and processing compared to conventional 1-2 channel eABR. Especially for some subjects, CI electrodes stimulate the auditory nerve and other nerves, such as the facial nerve. In contrast to stimulus uncorrelated artifacts as in acoustic ABR or FFR, the CI triggered facial nerve response cannot be averaged out with more repetitions. To our knowledge, up to date no method has been described in the literature to suppress such artifacts if they contaminate the eABR. For this case, our multi-channel eABR routine with ICA is a new possibility for extracting the standard eABR, an FFR, or the BIC in these subjects.

Poster 8

Measuring the latency of the frequency following response through group delay

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We tested the feasibility of measuring different sources of frequency following response (FFR) generation using different electrode montages with group delay (GD). One montage was vertically orientated (7th Cervical vertebra to high forehead) and the other was horizontally orientated (left mastoid to right mastoid). GD is the change in phase across frequency in the output of a system relative to the input phase spectrum. In a linear system, the phase spectrum should decrease linearly with increasing frequency. The steeper the function slope, the longer the delay of the output.

Stimuli were amplitude-modulated tones centred at 576 Hz. Five different modulation rates were tested (85, 100, 115, 130 and 145 Hz) separately in blocks of 3200 sweeps. GD was calculated across the FFR in the five conditions at the modulation rates, lower and upper side-tone frequencies separately. The presence of an FFR component was defined by an on-frequency magnitude three times greater than the mean off-frequency magnitude (noise estimate). For each set of FFR points (modulation, lower side-tone, or upper side-tone) phase was unwrapped such that the residual error to a linear fit was minimised. The function slope (taken as GD) was restricted to values between -0.001 and -0.020 (1 to 20 ms latencies).

Twenty-three young, normal-hearing listeners were tested, but not all exhibited sufficient FFR points to provide a complete GD dataset. Due to the unbalanced dataset, paired t-tests were used to compare vertical and horizontal montage GDs separately for modulation FFR, lower side-tone FFR and upper side-tone FFR (N=10 for each t-test). For modulation FFR and upper side-tone FFR, vertical GD was larger than horizontal GD, but not significantly so. For lower side-tone FFR, the vertical GD was significantly larger than the horizontal GD, even after Bonferroni correction.

The consistently longer GD for the vertical montage than the horizontal montage supports the hypothesis that the vertical montage is measuring, at least predominantly, an FFR generation source later in the auditory pathway than the horizontal montage is measuring. However, the large variability between subjects (particularly for modulation FFR) makes it difficult to determine specific generation sites.

Poster 9

Intact brainstem encoding but impaired identification of lexical tones in congenital amusia: Evidence from Cantonese speakers

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Congenital amusia is a neuro-developmental disorder of musical processing that often impacts speech processing. It remains debated at what stage(s) of auditory processing deficits in amusia arise. In this study, we investigated whether amusia originates from impaired subcortical pitch encoding in the brainstem. Ten Cantonesespeaking amusics and 10 matched controls listened to six Cantonese tones passively (3000 sweeps each) while their frequency-following responses (FFR) were recorded. All tones were carried by the same Cantonese syllable /ji/, but signified distinct word meanings (Tone 1, high-level, 'doctor'; Tone 2, high-rising, 'chair'; Tone 3, mid-level, 'meaning'; Tone 4, low-falling, 'son'; Tone 5, low-rising, 'ear'; Tone 6, low-level, 'two'). Apart from FFR recordings, all participants also completed a behavioral task in which they were required to identify the words that corresponded to the six Cantonese tones. The results indicated no evidence of abnormal brainstem encoding of linguistic pitch in amusics when compared to controls, as measured by stimulus-to-response correlation, signal-to-noise ratio, and frequency error. In contrast, a significant group (amusic vs. control) by tone (Tones 1-6) interaction was observed for the tone identification task, with amusics exhibiting significantly lower identification rates than controls for Tone 5 but not for the other tones. Analysis of the tone confusion matrix suggested that amusics were more likely than controls to confuse between tones that share similar acoustic features, such as Tones 2 and 5 (two rising tones), 3 and 6 (two level tones), and 4 and 6 (two low tones). Interestingly, this deficit in lexical tone identification was coupled with no evidence of abnormal brainstem encoding of the same tones. Together, our results suggest that the amusic brainstem is functioning normally, while higher-order linguistic pitch processing is impaired in amusia. This finding has significant implications for theories of central auditory processing, and calls for further investigations into how stages of auditory processing interact in the human brain.

Acknowledgements
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Poster 10

Frequency Following Response may reflect auditory spatial processing (ASP) in the brainstem

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Objective: Listening in an environment with a heavy acoustic load is quite challenging even for people with normal hearing. Speech recognition is remarkably improved when there is an angular separation between target and distracters (spatial release from masking (SRM)) in an auditory spatial scene. This process is dependent on the central auditory nerve system's ability to benefit from spatial cues, e.g. interaural intensity and time differences (IID and ITD) and spectral cues. We examined whether the Frequency Following Response (FFR) can be used to objectively measure this process, and the effects of different stimulus SNRs and the amount of the subject's participation.

Methods: An FFR was recorded in three EEG channels using a target vowel /u/ (250 ms duration). This stimulus was presented diotically in co-located (at 0 degrees azimuth) and spatially separated (±90 degrees) one-talker two-discourse maskers. Eighteen normal- hearing adults participated. The sound level was 60 dB SPL, with SNRs set at -5, 0, and 5 dB. To keep the participant's attention, deviants were randomly introduced, which needed to be counted by the subject. The stimulus rate was 2.85/s. Data was filtered between 50 and 3000 Hz. An analysis window of 270 ms and a bin width analysis of 5 Hz were applied.

Results: A significant interaction effect was found between stimulus SNR and SRM, with a significant effect of SRM only obtained at -5 dB SNR ($p=0.03$), where spatially separated maskers resulted in significantly larger FFR amplitude (a mean increase of 34.4 % with 95% confidence intervals (CIs) between 7.7 and 61.1%). This is equivalent to a 3.7 dB increase in stimulus SNR. We found a significant effect of participation ($p=0.004$) with larger FFR amplitude when actively focusing on the target (36.8 +/- 25.7 % increase with mean and 95% CIs), with larger FFR amplitude when actively focusing on the target. However, no significant interactions were found between spatial separation and the level of participation. This might be beneficial when testing younger subjects for their ability to spatially separate targets from maskers.

Conclusion: Binaural processing relevant to spatial separation may be reflected in the phase locked neural activity in the brainstem suggesting that spatial processing typically starts early in the central auditory nerve system, regardless of one actively monitoring the target stimuli. Spatial separation is most noticeable in difficult listening environments as the effects were statistically significant at the lowest SNRs only. FFR is a possible objective tool to evaluate auditory spatial processing and its disorder (ASPD), and to follow up the spatial auditory training in adults and young children.

Poster 11

<<Tim's abstract>>

Poster 12

Frequency Following Response to Interaural Phase Changes

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Hearing loss in one or both ears can decrease the ability to use binaural cues, potentially making it more difficult to understand speech and to localize sounds. Thus, it is important for both scientific and clinical purposes to find objective measures of binaural processing. In this study we developed an objective measure to assess binaural processing; specifically, we measured frequency following response to abrupt interaural phase changes (FFRIPCs) imposed on amplitude modulated signals in normal hearing listeners. The phase of the carrier signal presented to each ear was manipulated to produce discrete Interaural Phase Changes (IPCs) at minimums in the modulation cycle. The phase of the carrier was symmetrically opposed in each ear. For example, when the carrier phase was set to +5.5° in one ear, it was set to −5.5° in the other ear, resulting in an effective Interaural Phase Difference (IPD) of 11°. The IPDs tested in this study ranged between 11 and 135°. IPCs were presented at three different rates (3.4, 6.8, and 13.6 switches/s) and the carrier was amplitude modulated using several rates (27 to 109 Hz). Measurements were obtained using an EEG system with two channels.

Recordings demonstrated that FFR-IPC could obtained from all participants in all conditions. However, the Signal-to-Noise Ratio was largest when IPCs were presented at 6.8 switches/s. FFR-IPC were largest generally for IPDs between 45 and 90°. Overall, FFR-IPC increased with modulation rate. We concluded that FFR-IPC can be used as a reliable objective measurement of binaural processing.

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Poster 13

A Comparison of Two Objective Measures of Binaural Processing

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There has been continued interest in the clinical measures of binaural processing. A commonly proposed objective measure is the binaural interaction component (BIC). The BIC is obtained typically by recording the auditory brainstem response (ABR) to monaurally and binaurally presented click sounds. The BIC is measured as the difference between the binaural response and the sum of the monaural responses (i.e., binaural - (left + right)). We have worked recently on developing an alternative, direct measure of sensitivity to interaural time differences - namely, a frequency following response to abrupt interaural phase change (FFR-IPC). In an amplitude modulated signal, the FFR-IPC can be observed when the interaural phase difference of the carrier is alternated periodically at minimums in the modulation cycle.

In this study we compared BIC and FFR-IPC measurements. We measured responses from normally-hearing subjects by using a 16 channel EEG system. Although all subjects displayed generally robust ABRs, the BIC was not reliably observed. In contrast, the FFR-IPC elicited a large response that was clearly observed in all cases. Additionally, the FFRIPC required only a five minute recording session, which was considerably shorter than the 30 min used for BIC measurements. Results showed that ABR and FFR-IPC responses were both observed most clearly from the same electrode locations - namely, differential recordings taken from electrodes near the ear (e.g., mastoid) in reference to an electrode near the vertex (Cz). Overall, we conclude that the FFR-IPC is more suitable than the BIC for clinical applications.

The research leading to these results has received funding from the European Union's Seventh Framework Programme (FP7/2007-2013) under ABCIT grant agreement number 304912.

Poster 14

Cortical influences on brainstem FFR during productions whilst speakers hear their own voice

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Falling and rising pitch on tonal stimuli is well represented in the brainstem's activity. The majority of studies that have shown this have been on tone perception. Also, with the exception of Krishnan et al.'s (2012) perceptual study and Walczak et al.'s (in press) shadowing study, research has not looked at interactions between brainstem and the cortical level. We want to use the robust representation of rising and falling tones at the brainstem to determine efferent control of speech production. The previous study (Walczak et al., in press) provided some evidence that showed in shadowing that early cortical activity is associated with fall control and later activity with rise control. They also showed that the cortical mechanisms responsible for fall control may directly influence the brainstem FFR signal's fidelity whereas rise control appeared to have an indirect effect on production control.

The current study focused on investigating the relation between the cortical and brainstem levels in falling and rising tones during self production. The goal was to see whether the techniques used to investigate shadowing could be employed to situations where the speaker heard their own voice (auditory feedback). This involved solving the tricky problem of generating a synch-pulse that was sufficiently precisely coordinated with the produced speech sound to allow sensible averaging (for the FFR and concurrent cortical activity). We report results demonstrating the success of our procedures for FFR responses and concurrent cortical measures. Results are reported on correlations between cortical components (early N1 component and later P2 component) and parameters reflecting the fidelity of the brainstem FFR.

Poster 15

Frequency-Following Responses of the Rat Inferior Colliculus to Narrowband Noises

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Objective: Auditory temporal fine structure processing is critical for pitch perception, auditory-object segregation, and vocalization (speech) perception. Frequency following responses (FFRs), which are sustained neuro-electrical potentials imitating input sound waveforms, are well suited to the study of fine-structure processing. Observations in humans show that narrowband noises with low center frequencies (500 Hz) induce both pitch perception and scalp FFRs. Theoretical models also predict that FFRs can be elicited in the auditory midbrain by narrowband noises and are useful for investigating binaural interactions. The objective of this study was to record FFRs elicited by narrowband noises from the rat inferior colliculus (IC) and to investigate the interaural correlation and ITD effects on binaural evoked FFRs.

Methods: FFRs evoked by narrowband noises (center frequency = 2 kHz) were recorded in rats' IC using stainless steel recording electrodes (10-20 kΩ) and both FFR amplitude and phase-locking value were analyzed. The FFR amplitude was calculated by fast-Fourier transform. The phase-locking value was estimate by both phase coherence and phase entropy of instantaneous phase series (extracted by Hilbert transform) between stimulus and evoked potential. The individual ITD curves were fitting by a theoretical cross-correlation model for the best delay value.

Results: (1) FFRs were reliably elicited by the narrowband noises in the rat IC and exhibited both a bandwidth effect and remarkable ipsilateral-stimulation dominance. (2) FFR amplitude was highly correlated with the phase-locking value between the FFRs and the eliciting noise. (3) Under zero ITD condition, both FFR amplitude and phase-locking value of interaural correlated condition were significantly higher than those of interaural uncorrelated condition. (4) Finally, when the binaurally presented narrowband noises were correlated and the ITD was varied between -1 and + 1 ms, both the FFR amplitude and the phase-locking value fluctuation in cyclic fashion with the period roughly equivalent to the reciprocal of the noise center frequency. Cross-correlation fitting results gave the best interaural delays at time points of ipsilateral leading side (range from 10 to 90 μs).

Conclusions: The temporal fine-structure of narrowband noises are represented by intracranially recorded FFRs. Particularly, IC FFRs, which are tightly related to phase-locking processes, are sensitive to both interaural correlation and ITD and consistent with the cross-correlation model.

KEY WORDS: fine structure, frequency-following responses, inferior colliculus, narrowband noise, phase-locking

Poster 16

Get rhythm! - Subtle violations in the rhythmical auditory stimulation have an impact on the human complex auditory brainstem responses

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In natural environment, relevant stimuli frequently occur in low-rate rhythmic streams. Moreover, tracking the rhythmic structure of auditory stimulation is crucial in speech segmentation and music perception. In order to facilitate processing of such inputs the brain operates in a "rhythmic mode", entraining its oscillations to pattern of external stimulation. Both animal and human studies have reported enhanced perceptual processing when acoustic or visual stimuli were presented in- versus out- of phase of task-relevant rhythm. Additionally, the mismatch negativity (MMN) of the human event-related potentials (ERPs) is elicited by various manipulations of temporal structure of the auditory stimulation, i.e. changes in stimulus duration, rise time, stimulus onset asynchrony (SOA), stimuli omissions or when altering the timing of complex acoustic patterns. Importantly, violating a regular SOA triggers deviance-related responses at earlier latencies than those of the MMN, i.e. in the Pa and Nb components of the middle-latency response range (MLR), circa 30-40 ms from the deviance onset. The aim of the current study was to examine the effects of fine parametric violations in the rhythmic structure of simple auditory stimulation on the complex auditory brainstem responses (cABR). We used a multi-oddball paradigm, with amplitude modulated sine waves, where standard stimuli always occurred at multiples of 312 ms from the onset of experiment (constant rate of 3.21 Hz) and 8 equiprobable types of deviants (p=0.16) breaking the temporal pattern, occurred either advanced or delayed with respect to the previous standard onset – 156, 195, 234, 273, 351, 390, 429 and 468 ms, respectively. A sequence not entailing a rhythmic organization was used as a control condition. Our preliminary results show that spectra of the cABR components phase-locked to the envelope of stimuli differ parametrically in the deviant vs. control condition.

Poster 17

Notes