Measuring the latency of the frequency following response through group delay

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Introduction
To improve understanding and potential clinical use of FFR, previous studies have attempted to locate FFR sources within the auditory system [1,3-9]. Knowing sources could help explain individual differences in hearing ability or diagnosis of hearing impairments. Physiological responses to clicks from the auditory nerve are earlier (~1-2 ms) [7] than responses from high frequencies (10-40 ms) [4]. Can FFR latencies tell us about the nature of phase locking at different sites in the auditory brainstem?

What is Group Delay?
Higher frequency tones progress through the phase of their cycles quicker than lower frequency tones. Different frequency tones move in and out of phase with time. Provided the frequency spacing between consecutive tones is close enough that their phases are less than one cycle apart, the phase relationships are unwrapped to tell the elapsed time. This is shown in Fig. 1.

Methods
Listeners
Trios of young listeners with audiometric thresholds below 25 dB HL.

Stimuli
AM tones were generated by summing equal-amplitude pure tones equidistant in frequency. The frequency spacing dictates the modulation rate. Five stimuli were used (Table 1).

Results
For each listener, the Discrete Fourier Transform (DFT) at the modulation frequency (Mod) was taken from the mean addition waveform. At the lower-side-tone (LST) and higher-side-tone (HST) frequencies, the DFT was taken from the mean subtraction waveform.

Was any FFR recorded?
FFR was accepted as present if the magnitude of the DFT was greater than the mean magnitude at frequencies surrounding it (noise floor) by 2.57 standard deviations. The phase of the data points that passed this criterion was unwrapped for Mod, LST, and HST group delays separately. Group delay was taken only if three or more data points passed.

Unwrapping the phase
All possible unwrapping possibilities that could occur between elapsed times of 0 ms and 20 ms were calculated. The unwrapping that had the best linear fit was selected and the slope of that fit was taken as the group delay.

Discussion
These results support previous claims that horizontal and vertical montages record FFR from earlier and later sources respectively [3, 9]. Here, we show this for FFR to the fine structure of AM tones, but this may not be the case for envelope FFR. It is possible that envelope encoding is not prominent until later in the brainstem pathway.

Conclusions
- Horizontally-recorded FFR to the fine structure of AM tones arises earlier in the auditory pathway than vertically-recorded FFR
- Envelope FFR did not differ in latency between montages
- FFR signal-to-noise-ratio was sometimes poor, and a reasonable group delay was not always calculable. Online quality check of data is recommended.

Further Study
A subsequent study will look at age-related changes in FFR. Measuring comparatively datasets from enough young and old listeners may prove to be too difficult, or impractical, for group delay to be useful. Studying age-related changes to sources of FFR through delay or latency may be problematic as ABR latency is complicated by interactions among gender, age, and hearing loss [2, 4, 5].

Instead, the coherence of phase locking in FFR across trials will be compared with behavioural measures of temporal processing across age [6]. To save time, all FFR conditions will be tested simultaneously with the composite stimulus in Fig. 5. Figure 6 shows some preliminary data.

Aim
To find out whether a horizontally-aligned electrode montage can record FFR from a peripheral source and a vertically-aligned electrode montage can record FFR from a central source, using group delay as an indicator of the response latency.

References