Online supplemental material, Tabachnick & Toscano, "Perceptual Encoding in Auditory Brainstem Responses: Effects of Stimulus Frequency," JSLHR, https://doi.org/10.1044/2018_JSLHR-H-17-0486

Supplemental Material S1

Filtering of ERP and ABR data

Processing and analysis of ABR data follow many of the same steps as those used to analyze cortical ERP responses. In particular, raw data is typically filtered to remove myogenic artifacts, skin potentials, and other sources of noise. For example, many researchers collecting data in unshielded environments apply a notch filter to eliminate power line noise. Low-pass filters are used to further reduce line noise or EMG artifacts, which are higher in frequency than brain activity (Luck, 2014). Finally, high-pass filters can eliminate slow skin potentials that arise from perspiration, which may make it difficult to see changes in brain activity and establish a flat baseline, especially for later components like the late positive potential (LPP; Hajcak et al., 2012). High-pass filtering can also improve the signal-to-noise ratio of data collected from electrodes with relatively high impedance (Kappenman and Luck, 2010).

However, filtering can also lead to spurious results. This is particularly true for high-pass filters. Several early ABR studies observed that different high-pass filters alter the morphology of ABR and middle latency responses (Kavanagh et al., 1984; Scherg, 1982). Kavanagh et al. (1984) found that ABR amplitude decreases with increasing high-pass filter cutoffs. In general, they recommend high-pass filter settings ranging from 15 Hz to 100 Hz, depending on which set of components are of interest, and on the purpose of the recording (i.e. detecting low-frequency hearing loss vs. calculating inter-wave latencies). Stapells and Picton (1981) examined the effects of high-pass filtering on the ABR by presenting subjects with 500 Hz tones and processing the data with different high-pass filters, ranging from 10 Hz to 100 Hz, with roll-off slopes from 6 to 48 dB/octave. The results indicated that, with greater high-pass filters and/or steeper roll-off slopes, the prominence of wave V (defined as the V′/V amplitude ratio) is reduced, and artifactual peaks sometimes emerge. Additionally, wave V latency decreases as the high-pass cutoff or roll-off slope increases. The issue of high-pass filtering has also recently received attention among cortical ERP researchers. Tanner et al. (2015) demonstrated that even a high-pass filter of 1 Hz can obscure real effects and create artifactual components in later cortical ERP responses, such as the N400 and P600.

In light of this, the current study used minimal high-pass filtering (1 Hz cutoff, 24 dB/octave rolloff). This approach was motivated primarily by standard practices in cortical ERP experiments. However, the high-pass filter cutoffs used in cortical ERP experiments are not necessarily appropriate for ABR data. Thus, we considered different high-pass filter settings in order to select a filter that would minimize distortion of the data. In order to illustrate the effects of high-pass filtering, we present click-evoked ABR data from a separate group of subjects (N=11), processed using seven different high-pass filter cutoffs. As in the main experiment, subjects provided informed consent and received monetary compensation or course credit for participation, and the same equipment and procedures were used for EEG recording.

Data processing

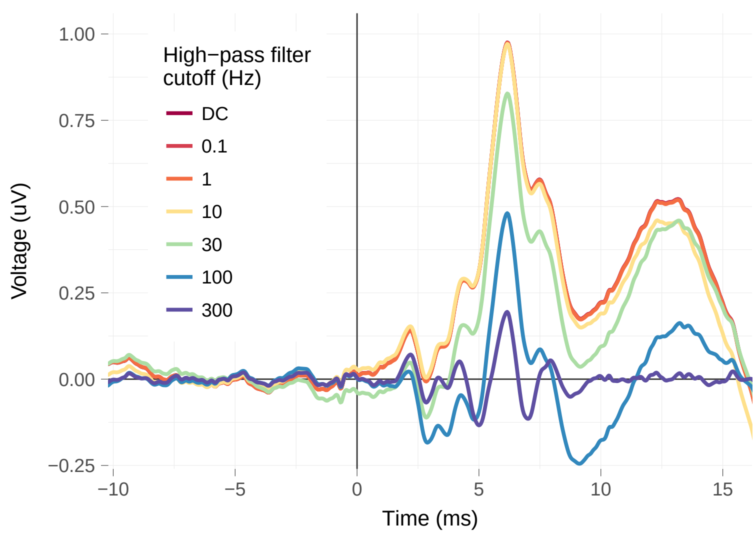
During analysis, seven filters, implemented in ERPLAB, were applied to each subject's continuous EEG data prior to epoching. Each filter setting used a Butterworth filter with a 24 dB/octave roll-off and included a low-pass cutoff at 3000 Hz. The first filtering condition (bandpass DC-3000 Hz) applied no further filtering. Artifact rejection was performed on this dataset and the list of trials marked for rejection was applied to the data for each other filter setting, so that the same trials were rejected across the filtering conditions. In order to determine the effects of filters previously used for processing ABR data, four other filter settings were examined: a high-pass filter at 10 Hz (i.e., bandpass 10-3000 Hz), a high-pass filter at 30 Hz (i.e., bandpass 30-3000 Hz), a high-pass filter at 100 Hz (bandpass 100-3000 Hz) and a high-pass filter at 300 Hz (bandpass 300-3000 Hz). In order to investigate more optimal filter settings, two additional filter settings were examined, based on those used by Tanner et al. (2015): 0.1 Hz high pass filter (bandpass 0.1-3000 Hz), and 1 Hz high-pass filter (bandpass 1-3000 Hz). Thus, seven versions of each listener's dataset were created with the following high-pass filters: low-pass only (DC), 0.1, 1, 10, 30, 100, and 300 Hz. After filtering, data were epoched, and trials were averaged to create ERPs. Wave V was measured as the mean voltage from 5–7 milliseconds, and linear mixed-effects models were used to evaluate effects of high-pass filter setting on mean amplitude and fractional area latency.

Results

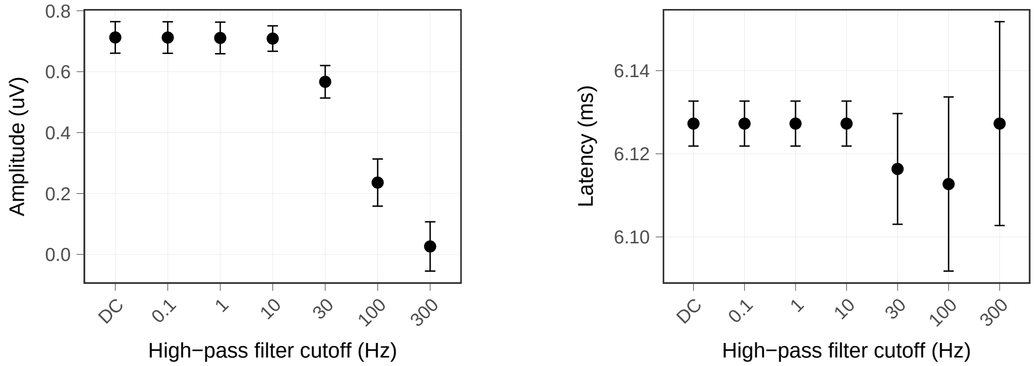
Listeners showed typical click-evoked ABR waveforms (Supplemental Material 1). Wave I is observed with a peak at ≈2-3 ms, and wave V with a peak at ≈6-7 ms. Both components appear to be affected by the different high-pass filter settings. In general, peaks are smaller with higher filter cut-off frequencies, consistent with previous observations (Stapells and Picton, 1981). This effect is most pronounced for the 100 and 300 Hz cut-offs, but can also be seen at the 10 Hz cut-off. The effects of the 0.1 and 1 Hz filters are substantially smaller. Component latencies are not strongly influenced by the high-pass filter settings, contrary to previous findings using analog filters (Stapells and Picton, 1981).

Mean amplitude and fractional area latency for wave V are shown in Supplemental Material 2. Overall, latency was only slightly affected by high-pass filtering. Mean amplitudes were affected to a larger extent, including a substantial decrease in wave V mean amplitude with filter settings >10 Hz. Mean amplitude of wave V was 0.71 μV with a 10 Hz cutoff, but 0.57 μV with a 30 Hz cutoff, and 0.24 μV with a 100 Hz cutoff.

These results were confirmed statistically using linear mixed-effects models. Log-transformed filter setting was entered as a scaled fixed effect (the DC condition was coded as 0.01 Hz, the cutoff of the anti-aliasing filter in the amplifier) with by-subject random slopes for filter setting. Model comparison was used to test for effects of high-pass filter setting on component amplitudes and latencies. The main effect of filter setting on wave V amplitude was significant ($\beta = -0.202$, SE = 0.047, $t = -4.32$, $p < 0.001$). The effect of filter setting on latency was not significant ($\beta = -0.003$, SE = 0.006, $t = -0.52$, $p = 0.607$). Thus, high-pass filter cutoffs >1 Hz begin to affect ABR amplitudes, and cutoffs >10 Hz can significantly reduce the amplitude of wave V. Given this, we selected a 1 Hz cutoff in the main experiment, allowing us to reduce noise in the data while preserving the morphology and amplitude of the ABR.



Supplemental Material 1. Grand average waveforms for click-evoked ABRs. Waves I, II, III, and V of the ABR are all visible in the waveform in the data with no high-pass filter applied (DC). Overall, increasing high-pass filter cutoffs leads to decreasing ABR amplitudes.



Supplemental Material 2. Wave V amplitude and latency as a function of high-pass filter cutoff. Amplitude is unaffected by high-pass filter cutoffs ≤10 Hz, but decreases significantly above that point. Latencies are preserved for cutoffs below 10 Hz.

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