



Research paper

Binaural interaction in human auditory brainstem response compared for tone-pips and rectangular clicks under conditions of auditory and visual attention



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ABSTRACT

Binaural interaction in the auditory brainstem response (ABR) represents the discrepancy between the binaural waveform and the sum of monaural ones. A typical ABR binaural interaction in humans is a reduction of the binaural amplitude compared to the monaural sum at the wave-V latency, i.e., the DN1 component. It has been considered that the DN1 is mainly elicited by high frequency components of stimuli whereas some studies have shown the contribution of low-to-middle frequency components to the DN1. To examine this issue, the present study compared the ABR binaural interaction elicited by tone pips (1 kHz, 10-ms duration) with the one by clicks (a rectangular wave, 0.1-ms duration) presented at 80 dB peak equivalent SPL and a fixed stimulus onset interval (180 ms). The DN1 due to tone pips was vulnerable compared to the click-evoked DN1. The pip-evoked DN1 was significantly detected under auditory attention whereas it failed to reach significance under visual attention. The click-evoked DN1 was robustly present for the two attention conditions. The current results might confirm the high frequency sound contribution to the DN1 elicitation.

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1. Introduction

Binaural interaction in the auditory system stands for a phenomenon that neuronal responses to binaural stimulation are different from the sum of those responses to the left and right monaural stimulations. Auditory brainstem response (ABR), as a far-field potential, can represent binaural interaction in auditory brainstem neurons. In animals, binaural interaction of ABR amplitudes (binaural response < sum of monaural responses) occurs at and after the fourth wave (Dobie and Berlin, 1979; Gardi and Berlin, 1981; Jewett, 1970; Melcher, 1996; Ungan and Yağcıoğlu, 2002;

Wada and Starr, 1989). One method to obtain ABR binaural interaction components (BICs) is the subtraction of summed monaural waveforms from binaural waveforms, resulting in a negative difference potential at the fourth wave latency. Terminology by Dobie and Berlin (1979) defined this negative difference potential as DN1 and the following positive difference wave as DP2. In humans, DN1 is found at the latency of wave V or later (Ainslie and Boston, 1980; Brantberg et al., 1999; Dobie and Norton, 1980; Jiang, 1996; Levine, 1981; Polyakov and Pratt, 1994; Wrege and Starr, 1981). Animal and human DN1 are functionally equivalent, and they are then considered to have the same generators (Fullerton et al., 1987; Riedel and Kollmeier, 2006; Ungan et al., 1997).

ABR binaural interaction can express the processing for sound lateralization in the auditory brainstem. Either interaural difference of time or intensity modulates systematically the latency and amplitude of ABR-BICs (Dobie and Berlin, 1979; Goksoy et al., 2005; Jones and Van der Poel, 1990; Riedel and Kollmeier, 2002, 2006; Ungan et al., 1997; Wrege and Starr, 1981). If compared to psychophysical performance in humans, the occurrence of DN1 agrees with perceiving a fused image for dichotic clicks (Furst et al., 1985; McPherson and Starr, 1995). Previous human studies explored the frequency contribution of sounds to ABR-BICs, by employing clicks

Abbreviations: A1, left earlobe; A2, right earlobe; ABR, auditory brainstem response; ANOVA, analysis of variance; BIC, binaural interaction component; Cz, vertex; EE, excitatory-excitatory; EI, excitatory-inhibitory; FFR, frequency-following response; ILD, interaural level difference; ITD, interaural time difference; LSO, lateral superior olive; M1, left mastoid; M2, right mastoid; MSO, medial superior olive; pe SPL, peak equivalent sound pressure level; SOA, stimulus onset asynchrony

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with either low- or high-passed masking noise (Levine and Davis, 1991; Polyakov and Pratt, 1999). They found that high frequency components of clicks (>2000 Hz) were principally contributing to DN1 evocation.

Compared to the consistent contribution of high frequency band to ABR binaural interaction, the low frequency contribution to the measure is showing discrepancy between studies. High-passed noise masking (>1000 Hz) to clicks diminished substantially ABR-BICs (Levine and Davis, 1991; Polyakov and Pratt, 1999), suggesting less contribution of low frequency band. On the other hand, studies employing tone pips and bursts revealed the increased amplitude and latency for DN1 in response to lower stimulus frequencies (Fowler and Horn, 2012; Fowler and Leonards, 1985; Ito et al., 1988), implying evident low frequency contribution to DN1 evocation. To solve the above discrepancy between studies, we can seek for improving the frequency specificity in stimuli. The procedures delivering a filtered masking noise to clicks are considered to preserve the frequency specificity for stimuli (Levine and Davis, 1991; Polyakov and Pratt, 1999). Contrary to this, tone pips and bursts used in the previous researches (Fowler and Leonards, 1985; Ito et al., 1988) had quite brief durations (≤ 2 ms) and rise-fall times (≤ 1 ms) resulting in poorer specificity for tonal frequency. A recent study using tone bursts with better frequency specificity (5-ms duration and 2-ms rise-fall times) demonstrated less contribution of low frequency band to DN1 (Fowler and Horn, 2012) compared to the previous studies (Fowler and Leonards, 1985; Ito et al., 1988). By employing longer stimulus durations and rise-fall times, we can then improve the frequency specificity for tonal stimuli and thus examine whether the better low frequency specificity would enhance ABR binaural interaction.

Another issue that has been unresolved in ABR binaural interaction researches is the attention contribution. In animal studies, given descending auditory pathways from the cerebrum to brainstem (Huffman and Henson, 1990; Winer, 2006) establishing multi-parametric corticofugal modulation (Suga, 2008; Suga and Ma, 2003), the change of auditory cortical activity is known to alter the auditory midbrain responses to binaural spatial cues (Nakamoto et al., 2008; Zhang et al., 2000; Zhou and Jen, 2005). In psychophysical experiments for sound localization, human participants are required to be alert and listen to binaural sounds (Sandel et al., 1955; Wightman and Kistler, 1992). Therefore, it is a valid assumption that a listening to binaural sounds might activate descending auditory pathways and then modulate ABR binaural interaction. At the present time, however, there is no direct evidence that has examined the above assertion. All studies for ABR binaural interaction thus employed either anesthetized animals (Dobie and Berlin, 1979; Fullerton et al., 1987; Gardi and Berlin, 1981; Jewett, 1970; Melcher, 1996; Ungan and Yağcıoğlu, 2002; Ungan et al., 1997; Wada and Starr, 1989; but except for Goksoy et al., 2005) or human participants without vigilance control by tasks (Ainslie and Boston, 1980; Brantberg et al., 1999; Dobie and Norton, 1980; Fowler and Horn, 2012; Fowler and Leonards, 1985; Fullerton et al., 1987; Furst et al., 1985; Ito et al., 1988; Jiang, 1996; Jones and Van der Poel, 1990; Levine, 1981; Levine and Davis, 1991; McPherson and Starr, 1995; Polyakov and Pratt, 1994, 1999; Riedel and Kollmeier, 2002, 2006; Wrege and Starr, 1981).

A feasible reason for ignoring the attention factor in ABR binaural interaction experiments would stem from the fact that ABR researches have traditionally failed to determine attention influences on the measure. Changes in vigilance level had basically no effect on ABR evocation (Amadeo and Shagass, 1973; Campbell and Bartoli, 1986). Many researches in humans obtained negative consequences for attention-related modulation of ABR (Collet and Duclaux, 1986; Connolly et al., 1989; Davis and Beagley, 1985; Gregory et al., 1989; Hackley et al., 1990; Picton and Hillyard,

1974; Picton et al., 1981). On the contrary, some researchers have found positive outcomes for attention-related ABR modulation in response to middle frequency (≤ 2000 Hz) tones (Lukas, 1980, 1981; Sörqvist et al., 2012). Consistent with this positive consequence, studies using frequency-following response (FFR) as a measure have provided evidence implying the attention effects at the auditory brainstem in humans (Galbraith and Arroyo, 1993; Galbraith and Doan, 1995; Galbraith et al., 1998, 2003; Hoormann et al., 2000, 2004). FFR is a sinusoidal response that corresponds to a stimulus fundamental frequency and it originates from phase-locked neural activities at or below the auditory midbrain level (Gardi et al., 1979; Marsh et al., 1972; Smith et al., 1975). FFR favors low-to-middle frequency (< 2000 Hz) tones (Gardi et al., 1979; Moushegian et al., 1973) which basically coincide with the dominant cues (< 1500 Hz) for human sound localization (Sandel et al., 1955; Wightman and Kistler, 1992). As expected from the above properties, binaural interaction in FFR has been established (Ballachanda and Moushegian, 2000; Daly et al., 1976; Hink et al., 1980; Krishnan and McDaniel, 1998). Since the brainstem neural population responsible for FFR conducts binaural processing in response to low-to-middle frequency sounds and further exhibits the attention-related modification, it is inferred that the brainstem neural activity showing low-to-middle characteristic frequencies and being responsible for ABR-BIC might be modulated by the attention task.

In order to identify attention factors that might affect ABR-BIC, two major problems existed in previous human studies for ABR binaural interaction which were lacking any task requirement for participants (Ainslie and Boston, 1980; Brantberg et al., 1999; Dobie and Norton, 1980; Fowler and Horn, 2012; Fowler and Leonards, 1985; Fullerton et al., 1987; Furst et al., 1985; Ito et al., 1988; Jiang, 1996; Jones and Van der Poel, 1990; Levine, 1981; Levine and Davis, 1991; McPherson and Starr, 1995; Polyakov and Pratt, 1994, 1999; Riedel and Kollmeier, 2002, 2006; Wrege and Starr, 1981). First, it was difficult to keep participant's vigilance level constant in a situation of ABR testing where participants were frequently required to close their eyes. Parts of participants were reported to be falling asleep during the study (Dobie and Norton, 1980; Ito et al., 1988; Jiang, 1996). Second, without any tasks it was failed to determine participant's attention focus during stimulation. Since the all studies above used only sound stimuli, it was likely that participants directed their attention to auditory modality. However, there remained the possibility that participants paid their attention to sensory modalities other than audition, to motor control for keeping their postures, or to own thinking such as mind wandering (Smallwood and Schooler, 2006). To resolve these problems in previous ABR-BIC studies, the present research compared the effects of auditory and visual attention tasks on ABR binaural interaction. This is based on the methodology of previous researches that employed both auditory and visual modalities for examining attention influences on ABR (Collet and Duclaux, 1986; Connolly et al., 1989; Davis and Beagley, 1985; Gregory et al., 1989; Hackley et al., 1990; Lukas, 1980, 1981; Picton and Hillyard, 1974; Picton et al., 1981; Sörqvist et al., 2012). Other attention factors were not treated independently in this study for avoiding a complication in the experiment.

The present study intended to examine the attention influence on ABR binaural interaction in response to a middle frequency tone pip (1000 Hz) having the improved frequency specificity compared to previous ABR binaural interaction studies. As a contrast, click-evoked ABR binaural interaction was recorded under the same condition. Two assumptions were tested in this study. First, the middle frequency tone pip would be difficult to elicit ABR binaural interaction whereas the click stimulation should establish the response. This is because the studies using a filtered masking noise

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