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EFFECTS OF CONGENITAL BLINDNESS ON THE SUBCORTICAL REPRESENTATION OF SPEECH CUES

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Abstract—Human modalities play a vital role in the way the brain produces mental representations of the world around us. Although congenital blindness limits the understanding of the environment in some aspects, blind individuals may have other superior capabilities from long-term experience and neural plasticity. This study investigated the effects of congenital blindness on temporal and spectral neural encoding of speech at the subcortical level. The study included 26 congenitally blind individuals and 24 normal-sighted individuals with normal hearing. Auditory brainstem response (ABR) was recorded with both click and speech synthetic 40-ms /da/ stimuli. No significant difference was observed between the two groups in wave latencies or amplitudes of click ABR. Latencies of speech ABR D ($p = 0.012$) and O ($p = 0.014$) waves were significantly shorter in blind individuals than in normal-sighted individuals. Amplitudes of the A ($p < 0.001$) and E ($p = 0.001$) speech ABR (sABR) waves were also significantly higher in blind subjects. Blind individuals had significantly better results for duration ($p < 0.001$) amplitude ($p = 0.015$) and slope of the V–A complex ($p = 0.004$), signal-to-noise ratio ($p < 0.001$), and amplitude of the stimulus fundamental frequency (F0) ($p = 0.009$), first formant (F1) ($p < 0.001$) and higher-frequency region (HF) ($p < 0.001$) ranges. Results indicate that congenitally blind subjects have improved hearing function in response to the /da/ syllable in both source and filter classes of sABR. It is possible that these subjects have enhanced neural representation of vocal cord vibrations and improved neural synchronization in temporal encoding of the onset and offset parts of speech stimuli at the brainstem level. This may result from the compensatory mechanism of neural reorganization in blind subjects influenced from top-down corticofugal connections with the auditory cortex.

Key words: congenital blind, speech, auditory brainstem response, temporal encoding, neural compensatory mechanism, top-down processing.

INTRODUCTION

Blind individuals can overcome some of their sensory impairments through the development of other sensory and cognitive capabilities (Wagner-Lampl and Oliver, 1994). According to some studies, congenitally blind individuals and those with early onset blindness have better development in a broad spectrum of cognitive and perceptual abilities (Rokem and Ahissar, 2009), including frequency discrimination of sound stimuli (Gougoux et al., 2004), identification of a sound source (Weeks et al., 2000; Gougoux et al., 2005), discrimination of temporal gaps, ability to distinguish small intervals of temporal gaps between two-noise bursts (Muchnik et al., 1991), judgment in sequences of auditory stimuli (Stevens and Weaver, 2005), identification of syllables and speech perception (Hugdahl et al., 2004), short-term memory (Hull and Mason, 1995), long-term memory (Roder and Rosler, 2003), and verbal skills (Rokem and Ahissar, 2009). In addition, it is possible that congenitally blind individuals process speech more rapidly than normal individuals, because they are more dependent on auditory language signals (Bliss et al., 2004). However, not all studies demonstrate superiority of these skills in blind individuals over those in normal-sighted subjects (Vecchi, 1998; Bliss et al., 2004; Kupers and Ptito, 2013).

According to studies on auditory event-related potential (ERP), the auditory cortex has higher excitability in blind subjects than in normal-sighted individuals. Roder et al. (1996). reported shorter latency of the N1 wave evoked 100 ms after auditory stimuli and shorter detection time of auditory stimuli in blind subjects compared with normal-sighted individuals. It is well known that the amplitude of EPRs decreases with an increased stimulus rate or a decreased inter-stimulus interval (ISI) (Roder et al., 1999; Hall, 2007). The time taken to reverse the primary amplitude is an index for excitability of the neural circuits (Roder et al., 1999). In this regard, the study by Roder et al. (1996) revealed that

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Abbreviations: ABR, auditory brainstem response; ERP, event-related potential; F0, stimulus fundamental frequency; F1, first formant; FFR, frequency following response; fMRI, functional magnetic resonance imaging; HF, higher frequency region; HL, hearing level; IC, inferior colliculus; MANOVA, multivariate one-way analysis of variance; RMS, root-mean square; sABR, speech auditory brainstem response; SD, standard deviation; SNR, signal-to-noise ratio; SPL, sound pressure level; SR corr, stimulus-to-response correlation; SR lag, stimulus-to-response lag.

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the N1 wave returns to its primary amplitude faster and the reaction time to the target auditory stimuli is shorter in blind individuals. Because both the primary and secondary auditory cortices are involved in creating the N1 wave, the higher excitability of the auditory cortex in blind individuals may be associated with enhanced perceptual skills (Elbert et al., 2002). This idea is further supported by evidence of reorganization in the auditory cortex after visual deprivation. For instance, in a magnetoencephalography (MEG) study during a response to auditory stimuli, expansion of tonotopic maps in the auditory cortex of blind subjects was observed (Elbert et al., 2002). In addition, a functional magnetic resonance imaging (fMRI) study showed a decreased hemodynamic response to auditory stimuli in the superior and middle temporal lobe of early-blind subjects compared with late-blind and sighted participants (Stevens and Weaver, 2009). In these studies, it was concluded that the auditory cortex of blind subjects processes stimuli more efficiently, at least under low-demanding task conditions. These behavioral and neurophysiological findings support the hypothesis that a stronger ability to recognize the basic characteristics of auditory stimuli, such as frequency, timing, and duration, by the congenitally blind may be caused by neural reorganization in the auditory cortex (Stevens and Weaver, 2009). Furthermore, brain imaging studies provide a neurobiological underpinning for the behavioral results (Kupers and Ptito, 2013). In two-positron emission tomography (PET) studies (Gougoux et al., 2005; Voss et al., 2008), activity of the occipital cortex was shown in the subgroup of early-blind subjects with superior performance in sound localization. However, this finding was not observed in sighted controls, late-blind subjects, and blind individuals with normal monaural sound localization abilities. Moreover, a highly significant correlation between the change in the BOLD (blood oxygen level dependent) response in the occipital cortex and performance in the monaural task was reported in the blind subjects, suggesting the effect of neural computations in the occipital cortex on the enhanced capacity to use monaural cues in congenitally blind subjects (Kupers and Ptito, 2013).

In humans, the auditory scene entails complex sounds that are rich in harmonic structures, dynamic modulations, and rapid spectro-temporal fluctuations. This complexity is also constructed from rigorous and unique temporal and spectral neural codes of the auditory brainstem, influenced by the activity of the afferent and efferent nuclei of the auditory system. The auditory brainstem has two general categories of time-locked response; transient and sustained. Transient responses result from the transient and non-periodic characteristics of a stimulus, and sustained time-locked responses result from only the non-periodic characteristics of a stimulus. Although, these basic response patterns can be evoked by click and tone stimuli, these stimuli are not suitable to elicit complex responses from the auditory brainstem (Skoe and Kraus, 2010).

There are many complex stimuli used to assess responses of the auditory nerve to spectral and temporal features of sound. For example, recording the speech auditory brainstem response (sABR) to the /da/ syllable is used in pre- and post-auditory training programs throughout a life span of some specific groups of individuals, such as musicians, dyslexic children, specific language impairments (SLIs), and those with disorders on the autism spectrum. These studies revealed that subcortical auditory processing does not have a specific hardware design, but that it has an elastic and formable nature from personal experience and cognitive capability in different domains such as language and music (Skoe and Kraus, 2010). Cortical response differences among congenitally blind subjects and those with early onset of blindness and normal-sighted individuals have been reported in many studies via different research methods. However, this is the first paper examining subcortical auditory function in congenitally blind participants. Specifically, this study presents new findings on the effect of visual sensory deprivation on temporal and spectral processing of /da/ speech stimuli at the brainstem level. The findings reveal the influence of auditory areas in both temporal and occipital cortices to modulate processing in the auditory brainstem through corticofugal connections and long-term neural plasticity in the human subcortex from visual sensory deprivation. Specifically, the study investigates whether or not congenital visual deprivation and greater emphasis on language stimuli have enhanced effects on processing speech cues through experience-dependent plasticity (Kraus and Chandrasekaran, 2010).

EXPERIMENTAL PROCEDURES

Participants

Twenty-six congenitally blind adults (26–40 years; mean ± standard deviation (SD) = 35.07 ± 4.51 years; 16 males) and 24 normal-sighted controls (26–40 years; mean ± SD = 33.08 ± 4.15 years; 14 males) participated in the study in the Newsha Hearing Institute in Tehran. Six other individuals were also assessed but were excluded from the study due to missing data or muscle artifact contamination. Congenitally blind subjects were selected from the Roudaki Center for the Blind according to the following inclusion criteria: pure-tone hearing threshold in both ears of a level equal to or less than 25-dB hearing level (HL) in octave band frequencies ranging from 250 to 8000 Hz (American National Standards Institute, 2004); results of acoustic reflexes and middle ear tympanometry (ear canal volume: 0.9–2.0 cm^3, static compliance: 0.3–1.5 mmho, and sound pressure level: ±50 dapa) (Shanks and Shohet, 2009) and word discrimination scores (WDSs) within normal limits. All individuals were educated, right-handed and monolingual native Persian speakers with no history of audiological or medical problems. Individuals in the blind group included those who were blind due to a peripheral lesion (such as retinal damage, immaturity and/or neural damage) or optic atrophy without any known neurological illness or brain injury (Hotting and Roder, 2009).