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Enhanced perception of pitch changes in speech and music in early blind adults

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ABSTRACT

It is well known that congenitally blind adults have enhanced auditory processing for some tasks. For instance, they show supra-normal capacity to perceive accelerated speech. However, only a few studies have investigated basic auditory processing in this population. In this study, we investigated if pitch processing enhancement in the blind is a domain-general or domain-specific phenomenon, and if pitch processing shares the same properties as in the sighted regarding how scores from different domains are associated. Fifteen congenitally blind adults and fifteen sighted adults participated in the study. We first created a set of personalized native and non-native vowel stimuli using an identification and rating task. Then, an adaptive discrimination paradigm was used to determine the frequency difference limen for pitch direction identification of speech (native and non-native vowels) and non-speech stimuli (musical instruments and pure tones). The results show that the blind participants had better discrimination thresholds than controls for native vowels, music stimuli, and pure tones. Whereas within the blind group, the discrimination thresholds were smaller for musical stimuli than speech stimuli, replicating previous findings in sighted participants, we did not find this effect in the current control group. Further analyses indicate that older sighted participants show higher thresholds for instrument sounds compared to speech sounds. This effect of age was not found in the blind group. Moreover, the scores across domains were not associated to the same extent in the blind as they were in the sighted. In conclusion, in addition to providing further evidence of compensatory auditory mechanisms in early blind individuals, our results point to differences in how auditory processing is modulated in this population.

1. Introduction

Congenital blindness is one of the models used to study long-term neuroplasticity. Indeed, signs of cerebral reorganization are found in the function and the structure of the brains of individuals who never saw or lost sight at an early age. For instance, the brain areas that are traditionally devoted to visual and multisensory processing are taken over by tactile processing (Burton et al., 2004; Weaver and Stevens, 2007), auditory processing (Kujala et al., 1995; Stevens and Weaver, 2009; Weaver and Stevens, 2007), or higher level functions such as language (Burton et al., 2003; Röder et al., 2002) and memory (Amedi et al., 2003; Bonino et al., 2008). Changes are apparent in the functional connectivity of these brain areas (Bedny et al., 2011; Collignon et al., 2011; Sani et al., 2010; Weeks et al., 2000). The neuroplastic reorganization of a congenitally blind adult's brain also manifests itself in changes in cortical thickness (Anurova et al., 2014; Jiang et al., 2009; Park et al., 2009; Voss and Zatorre, 2012), volume (Lepore et al., 2010; Pan et al., 2007; Park et al., 2009; Ptito et al., 2008), and structural connectivity (Park et al., 2007; Shimony et al., 2006; Shu et al., 2009a, 2009b; Yu et al., 2007).

In addition, behavioral differences are observed in blind adults when they process auditory information. Studies have shown that some blind participants have better capacities to localize sounds and to navigate in space using sound information (Teng et al., 2012; Voss et al., 2011). In the domain of speech, where vision usually plays an important role - during speech acquisition (Kuhl et al., 1992) and in face-to-face communication (Hubbard et al., 2009; McNeill, 1992; Sumby and Pollack, 1954) - compensatory mechanisms in the auditory

Abbreviations: FDL, frequency difference limen; f0, fundamental frequency; F1, first formant; F2, second formant; dB, decibel; Hz, Hertz; ms, millisecond

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modality are also evident. Indeed, visually deprived adults are better than sighted adults in the acoustic discrimination of syllables (Hugdahl et al., 2004) and vowels (Ménard et al., 2009), and in the perception of words in noise (Muchnik et al., 1991; Niemeyer and Starlinger, 1981); they also respond faster than controls in a lexical decision task (Röder et al., 2003). Blind adults also show stunning abilities to understand artificially accelerated speech up to a rate of 18 syllables/sec (Dietrich et al., 2011, 2013; Hertrich et al., 2013a, 2013b, 2009; Moos and Trouvain, 2007; Trouvain, 2007) compared to rates of 8–10 syllables/sec in sighted controls (Trouvain, 2007). Neuroimaging studies reveal that the cerebral networks that are recruited for this kind of task differ from the recruited areas in controls with, for instance, cross-modal recruitment of visual and multisensory areas in the blind (Arnaud et al., 2013; Burton et al., 2003, 2002; Dietrich et al., 2013; Hertrich et al., 2009).

Regarding pitch processing, neuroimaging studies have drawn links between, on one hand, performance on pitch processing tasks, and on the other hand, changes in the cerebral structure, e.g. cortical thickness, grey matter concentration and magnetization transfer ratio in occipital areas in blind participants (Voss et al., 2014; Voss and Zatorre, 2012). However, a fMRI study of the processing of pitch vs. spatial properties of sounds failed at identifying cross-modal activity of occipital areas specific to pitch processing, as opposed to the spatial processing of the same sounds, (Collignon et al., 2011) and in a MEG study on speech perception group differences between blind and sighted in pitch periodicity-correlated activity was found in the primary auditory areas of the blind and not in occipital areas (Hertrich et al., 2013b).

The rationale behind the current study was to test if enhanced pitch processing abilities in the blind are specific to pure tones or if it extends to complex sounds such as speech sounds. Indeed, previous works have found better processing of speech for higher level tasks such as better understanding of accelerated sentences, better identification of syllables or vowel contrasts but we ignore if enhanced perception of physical properties of the sounds, such as pitch, is enhanced for speech sounds in the blind. In addition to testing enhanced pitch processing in speech sounds in the blind, we question here the impact of experience or familiarity with the stimuli (native vs. non-native) and domain (speech vs. music). To our knowledge, the question of domain specificity of the auditory advantage of the blind has not been tested before.

In summary, even though there is evidence of auditory compensation in speech processing in the blind, the full extent of these enhanced abilities is not well known. Studies have shown better pitch discrimination thresholds (Gougoux et al., 2004; Rokem and Ahissar, 2009; Voss and Zatorre, 2012; Wan et al., 2010) and better temporal consolidation (Stevens and Weaver, 2005) in the blind compared to controls for pure tones. There are, however, few studies that have investigated basic auditory acuity of the blind for sounds other than pure tones, so it is still unclear if this is a domain-general or domain-specific ability. Enhanced processing of basic acoustic cues in speech could contribute to the enhanced ability to process speech observed in blind adults (e.g. ultra fast speech comprehension). A challenge when comparing the processing of sounds from different categories (e.g. music, speech etc.) is the choice of comparable stimuli. In the current study, we chose to compare processing of music units (isolated instrument notes) and speech units (e.g. isolated vowels).

The objective of this study was to further define the extent of enhanced auditory processing in congenitally blind individuals. Specifically, we focused on the auditory acuity of congenitally blind adults for pitch discrimination of complex sounds coming from different acoustic domains (speech and music). We included native and non-native speech sounds to assess the impact of stimulus familiarity. The first experiment focused on the selection of a personalized set of native and non-native vowel stimuli for each participant. In the second experiment, participants underwent an adaptive pitch discrimination task on the individually selected stimuli -native and non-native vowels - as well as on non-speech sounds - instrument sounds and pure tones. The experimental design allowed for the comparison of pitch discrimination thresholds between groups (blind and control).

2. Experiment 1 – Vowel identification and rating

2.1. Methods

2.1.1. Participants

Fifteen congenitally (onset of blindness during or before birth, n = 12) and early (onset of blindness before 12 months, n = 3) blind adults and fifteen sighted adults (control group) ranging from 24 to 64 years of age participated in this study (see Table 4 for demographic information on participants including cause and onset of blindness for blind participants). All participants were native speakers of Canadian French and self-identified as monolinguals. The two groups were matched on: age, gender, number of years of education, and number of years of formal musical training. The experiment was performed in accordance with the ethical standards in the 2004 Declaration of Helsinki and requirements of the Faculty of Medicine, McGill University. The consent form was read to the blind participants. All participants provided written consent.

2.1.2. Experimental design

The objective of the study was to determine, for congenitally blind participants and controls, the frequency difference limen (FDL) of pitch-direction identification for native vowels, non-native vowels, instrument sounds and pure tones. The experiment was divided into two parts. The objective of the first part was to create a personalized corpus of native and non-native vowels for each participant. Participants had to identify if the vowels they heard were 'French' or 'non-French' and rate them based on their quality (see details below). Then on a second visit, participants performed the pitch-direction identification task on a personalized set of two native vowels, two non-native vowels and three non-speech sounds (pure tone, cello, piano).

2.1.2.1. Corpus creation

2.1.2.1.1. Stimuli. During the first visit, participants listened to a set of 108 vowels. Nine variants of each of the 6 native (French) vowels /i/, /y/, /u/, /e/, /ə/, /a/, and 9 variants of each of the 6 non-native vowels /ɨ/ /ʉ/ /ɯ/ /ʊ/ /ɤ/ and /ʌ/ (see Fig. 1) were selected for this part and presented to each participant. The vowels were synthesized using the

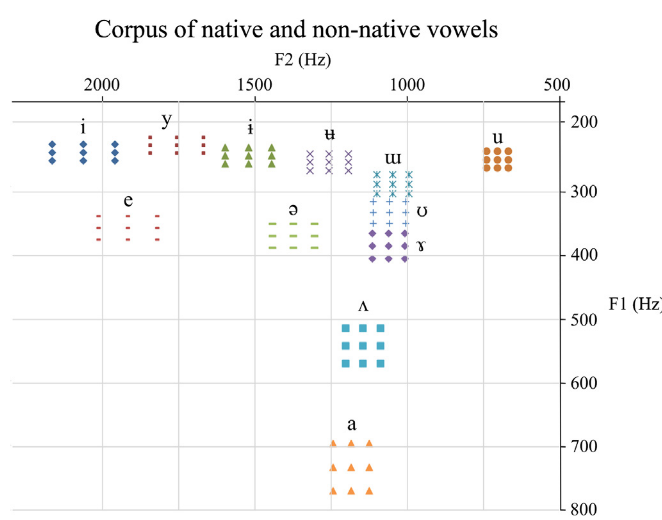

Fig. 1. Native and non-native vowels used in identification and rating task. Nine tokens of each of 6 native (i y u e ə a) and 6 non-native (ɨ ʉ ɯ ʊ ɤ ʌ) vowels were presented to participants in an identification and rating task. For each vowel category, eight variants were then synthesized around the reference prototype by modifying the values of the first two formants in 5% steps.