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Research paper

Interaction in the perceptual processing of interaural time and level differences

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Abstract

Phillips and Hall [Psychophysical evidence for adaptation of central auditory processors for interaural differences in time and level, Hear. Res., 202 (2005) 188–199.] recently described the frequency-specific, selective adaptation of perceptual channels for interaural differences in level (ILD) and time (ITD). Psychometric functions for laterality based on ITD or ILD were obtained before and after exposure to adaptor tones of two frequencies presented alternately and highly lateralized to opposite sides. Following adaptation, points of perceived centrality (PPCs) were displaced towards the sides of the adaptor tones, and in opposite directions for the two frequencies. That is, laterality judgements showed a shift away from the adapted side, particularly for test cue values near the middle of the range. These data were congruent with a two-channel, opponent-process model of sound laterality coding. The present study used the same general paradigm to explore the independence of perceptual ITD and ILD processing. Psychometric functions for laterality based on ITD or ILD were obtained for each of two frequencies concurrently, before and after exposure to adaptor tones lateralized using the *complementary* cue. Once again, PPCs derived from the psychometric functions were displaced towards the sides of the adaptor tones, consistent with an opponent-process account of sound laterality coding. The size of the adaptation effect was at least as great as that described in the earlier study. Thus, a quarter cycle ITD adapting stimulus effected a 3 dB shift in the mean ILD-based PPC, and a 12 dB ILD adapting stimulus effected a 100 μs shift in the mean ITD-based PPC. These data offer new evidence concerning interaction in the processing of ITDs and ILDs.

Keywords: Interaural level difference; Interaural time difference; Selective adaptation; Auditory lateralization; Opponent process model

1. Introduction

Phillips and Hall (2005) recently presented psychophysical evidence for a rapidly-induced and robust adaptation of central auditory processors for interaural time (ITD) and interaural level differences (ILDs). Briefly, psychometric functions for sound laterality based on ITDs or ILDs were obtained for tone pulses of each of two frequencies before and after exposure to alternating adaptor tones of the same two frequencies highly lateralized to opposite sides. Following only seconds of exposure to the adaptor tones, psychometric functions for laterality based on ITD or ILD were shifted in the directions of the adaptor tones. This suggested an opponent-process model of sound laterality coding based on two spatial channels. The spatial channels are thought to be centered in the left and right auditory hemifields, respectively, with medial borders that span the midline and extend slightly into the contralateral hemifield (after Boehnke and Phillips, 1999). According to this view, laterality judgements for sources near the midline depend on the relative outputs of the two channels, so adaptation of either channel, perhaps through a gain-control mechanism (Kashino and Nishida, 1998), shifts the point

Abbreviations: dB, deciBel; HL, hearing level; Hz, Hertz; ILD, interaural level difference; ITD, interaural time difference; L, left; LSO, lateral superior olive; μs, microsecond; MSO, medial superior olive; PPC, point of perceived centrality; R, right; SPL, sound pressure level

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of perceived centrality toward the adapted side. This binaural cue processing is done on a frequency-specific basis (Kashino and Nishida, 1998; Phillips and Hall, 2005).

This general model, i.e., of human auditory spatial perception being based on two hemifield-tuned channels, is consistent with previous neurophysiological studies in animals which suggested that each side of the auditory forebrain encodes spatial information largely for the contralateral auditory hemifield (McAlpine et al., 2001; Middlebrooks and Pettigrew, 1981; Phillips and Irvine, 1981; Phillips and Brugge, 1985; Stecker et al., 2005). Behavior-lesion studies show that unilateral auditory forebrain ablations result in sound localization deficits for sources in the auditory hemifield contralateral to the lesion (Jenkins and Masterton, 1982; Jenkins and Merzenich, 1984; Kavanagh and Kelly, 1987; Heffner, 1997), suggesting that the neural substrates of the left and right perceptual channels may reside in large part in the right and left cerebral hemispheres, respectively. A quite different, population model has been derived from work in the barn owl, in which neural maps of auditory space are formed by the topographic arrangement of cells according to the locations of their spatial receptive fields (Knudsen and Konishi, 1978). Individual receptive field locations are formed by joint sensitivity to different ranges of ITDs and ILDs (Moiseff and Konishi, 1983). There has been a psychophysical attempt to explore the possibility that such a population code might be operating in human beings (Carlile et al., 2001), but neurophysiological studies have not shown the existence of a "space map" in the cortex of any mammalian species examined (see Boehnke and Phillips, 1999; Middlebrooks et al., 1998; Stecker et al., 2005).

In Phillips and Hall (2005) study, adaptation of central processors of ITDs and ILDs were examined in separate experiments. A further question concerns the existence of any interaction between the two processing systems. It is possible, for example, that ITDs and ILDs are encoded in separate pathways (notably those involving the medial and lateral superior olivary nuclei, respectively: Tsuchitani and Johnson, 1991; Irvine, 1992), and contribute to laterality perception independently. If the processing of ITD and ILD are independent, then one might expect little or no interaction between the processing of the two cues to be revealed by adaptation of either mechanism. On the other hand, it is possible that the outputs of those processors ultimately converge at a higher level. At that higher level, processor output (a decision about source laterality or location) may carry no information about the identity of the cues (ITD or ILD) on which the decision was based. Within such an architecture, a paradigm like Phillips and Hall's could induce adaptation either at the (low) level of ITD or ILD coding, or at a stage after the convergence of information from those two coding systems (high level). In either case, adaptation of the system processing one cue could affect the perceptual performance based on the other.

The purpose of the present study was to address these questions. We obtained psychometric functions for laterality based on ITD or ILD before and after exposure to adaptor tones highly lateralized using the complementary cue. Our data reveal the effect of adaptor tones to be at least as strong as that described by Phillips and Hall (2005).

2. Methods

2.1. Subjects

A total of eight adults (5 female) with ages from 20 to 39 years served as participants. All subjects met the following audiometric criteria: better than 20 dB HL at octave frequencies from .25 to 8.0 kHz, and no HL difference between the ears of greater than 5 dB (one testing step) at any frequency. The studies in this report received ethical approval from Dalhousie University's Research Ethics Office, under protocol #2004-860.

2.2. Stimuli and apparatus

Stimuli were tones digitally synthesized at a sampling frequency of 44,100 Hz, and presented with Sennheiser HD25-1 headphones. Stimulus delivery and data collection and analysis were performed on an Apple 8600 Powermac computer using Matlab™ (the Mathworks). Tones were of frequencies 260 and 570 Hz, and were 260 ms in duration including 10 ms linear rise/fall times. Stimulus amplitudes were at a comfortable listening level, in the range from 70 to 78 dB SPL (A-weighted). Subjects sat in an Eckel sound-attenuating booth, before a computer monitor and keyboard. The computer CPU was located outside the booth. Subject responses were made via the keyboard.

2.3. Procedure

The general procedures were the same as those described in Phillips and Hall (2005). Each testing block consisted of 72 trials (4 repetitions $\times$ 2 frequencies $\times$ 9 cue values) presented in random order. Test tone ITD cue values were -180 to 180 μs in steps of 45 μs. Test tone ILD cue values were -8 to 8 dB in steps of 2 dB. Adaptation tone cue values were $\pm$ an interaural delay of quarter cycle of the tone frequency (453 and 975 μs for 570 and 260 Hz, respectively, imposed as delay in the complete tone pulse) (ITD), or $\pm$12 dB (ILD). Blocks were performed in pairs, one pre-adaptation and one post-adaptation. One pre- and one post-adaptation block pair was performed in a session, and sessions were separated by at least one intervening day. Note that because the ITD was produced by imposing a delay on the whole stimulus to one ear, it is unclear whether the resulting percept is lateralized on the basis of the envelope delay or the moment-by-moment interaural phase delay of the carrier. In what follows, we assume that it is predominantly the latter, but this is an empirical question.

The trial structure for a pre-adaptation block was as follows. Three high-pass (>2000 Hz) dichotic clicks (interclick interval = 60 ms) served to orient the subject to the midline. These were followed after 500 ms by the presentation of a single tone. The task of the subject was to report (using the keys "1" or "2") whether the tone was experienced as located to the left or to the right of midline. The intertrial interval was 500 ms.

Post-adaptation blocks had the same format, except that the whole block was preceded by an adaptation sequence, and each trial within the block was preceded by a shorter duration refresher adaptation sequence. The adaptation sequence consisted of repeated alternating tones (260 and 570 Hz) presented with positive and negative values of the adapting cue. Like the test tones, the adaptation tones were 260 ms in duration, and were presented with 40 ms of silence between them. For the subject, the experience of the adapting sequences was of high and low tones alternating in intracranial location between strongly left and strongly right.