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Loudness adaptation measured by the simultaneous dichotic loudness balance technique differs between genders

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ABSTRACT

Loudness adaptation was measured using the classic simultaneous, dichotic loudness balance technique. A 6-min continuous tone was introduced using headphones to a participant's *adapting ear*. Immediately upon presentation of the tone and at 1-min intervals, participants adjusted the sound level of a tone of the same frequency in the contralateral *control ear* until both tones sounded equally loud. The control ear, which was otherwise retained in silence, measured adaptation in the adapting ear. As the constant-sound level stimulus to the adapting ear continued, the sound level that a participant selected to produce equal loudness between ears decreased, oscillating towards an apparent asymptotic value. This value was used to calculate total decibels of adaptation. The magnitude of female adaptation exceeded that of males at all time points measured following stimulus onset. The ratio total dB of adaptation to dB SL of the test tone may provide an empirical estimate for the loudness exponent, n, seen in Stevens' power law, $L = k\varphi^n$, which relates the intensity of a pure tone, φ, to the loudness of the tone, L. Since dB of adaptation for females was greater than that of males, female n-values exceeded those of males, in accordance with previous research.

1. Introduction

The decrease in sensation with increased duration of stimulus presentation, or psychophysical adaptation, is known to exist in many modalities (e.g., taste, vision, and temperature). In audition, loudness adaptation has been studied using binaural and monaural methods. Von Békésy (1929, 1960) introduced the binaural technique for measuring loudness adaptation; Hood (1950) named and developed the simultaneous dichotic loudness balance (SDLB) method. Later studies describe changes in the magnitude of auditory adaptation with changing frequency and sound level (Jerger, 1957), with varying on-time and off-time of the adapting stimulus (Small and Minifie, 1961) and when the level of the adapting tone differs from that of the pre- and post-adaptation tones (Weiler et al., 1972). Using (binaural) SDLB methods, researchers report that adaptation increases with increasing stimulus level up to about 60 dB.

Simple adaptation, the decline in loudness to a continuous tone presented alone, is measured using, for example, the (monaural) method of successive magnitude estimation (Canévet et al., 1985). Utilizing this technique, a 6-min continuous tone declines by approximately 20% at 40 dB SL (Hellman et al., 1997). Little adaptation (about 10%) is reported for test levels of greater than 40 dB SL. Work by Scharf and colleagues (e.g., Canévet et al., 1983, 1985) suggests that adaptation measured by the SDLB technique is induced; that is, the presence of a comparison tone presented to the contralateral ear is responsible for eliciting observed adaptation. Differing experimental techniques yield different measures of loudness decline; however, auditory adaptation, when measured by a valid test procedure such as the SDLB, is real and reproducible.

There are several reports of gender differences in psychophysical, physiological, and physical measures of the auditory system, of which McFadden (1998) provides an extensive review. Corso (1959) reports one of the first systematic investigations of hearing thresholds between genders. He measured threshold levels of 500 participants ranging in age from 18 to 49 years, at frequencies ranging from 250 to 8000 Hz. Women tend to have lower auditory thresholds than men. This difference becomes statistically significant at higher frequencies (above 3 kHz) for the 18–40 year old range (Corso, 1959). During localization tasks, males tend to

Abbreviations: ANOVA, analysis of variance; BC, bone conduction; dB, decibel; HL, hearing level; IA, interaural attenuation; OAE, otoacoustic emission; SDLB, simultaneous dichotic loudness balance; SEM, standard error of the mean; SL, sensation level

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discriminate between small differences in interaural time and level differences more accurately and consistently than females (Langford, 1994). However, males incur greater permanent noise-induced hearing loss (Royster et al., 1980). Using a tone-identification paradigm, Sagi et al. (2007) report gender differences in the psychophysical parameter, n, found in Stevens' power law, $L = k\varphi^n$, relating the loudness of a tone, L, to the physical intensity of the tone, φ. Male exponents are found to be about 25% smaller than those of females, indicating differences in loudness perception. Recently, Neuhoff et al. (in press) report gender differences in the perception of approaching sounds. Although all participants tended to underestimate time-to-arrival of the sound, female underestimation was significantly greater. Physiologically, females tend to have greater click-evoked otoacoustic emissions (OAEs) than males (by 2–3 dB; McFadden et al., 1996) and a greater number of spontaneous OAEs (Talmage et al., 1993). These differences are apparent in neonates (e.g., Burns et al., 1992). Wave V of the auditory brainstem response tends to have a greater amplitude and shorter latency for females than their male counterparts (Don et al., 1993). Several studies also reveal anatomical differences in the auditory system between genders. For example, Miller (2007) reviewed 11 studies examining 198 cochleae and found that, on average, male cochleae are longer than those of females by 3.36% or 1.1 mm. Although there is a broad literature on gender differences in hearing, we found no reports of gender differences in the perception of long-duration tones measured using either monaural or binaural techniques.

We selected the SDLB technique for several reasons. Norwich (1993, p. 189) studied the relation between loudness adaptation, measured using the SDLB technique, and the loudness exponent, n. He reports a linear relationship between dB of adaptation and on-time of a continuous adapting stimulus, in logarithmic units, from which the value of the loudness exponent can be obtained. Also, as indicated above, Sagi et al. (2007) report that n can be evaluated to within a multiplicative constant by using a sound-level identification paradigm (i.e., without using traditional subjective assessment such as magnitude estimation). Participants were required to identify the dB-value of unknown tones. From the errors they made (signifying a loss of information between source and receiver), estimations of the relative values of n were made. The mean value of n for females measured by this technique is greater than the mean value for males. We sought an independent method of confirming these earlier results that also does not make use of magnitude estimation.

The present paper sets out to test the hypothesis that gender differences exist in auditory adaptation measured using the SDLB technique. We then present an empirical relationship between dB of adaptation and the loudness exponent, n.

2. Materials and methods

2.1. Overview

We explored the process of loudness adaptation in a group of student participants using the SDLB procedure. It essentially used the *control ear* (retained in silence) to monitor the level of (induced) adaptation in the contralateral *adapting ear*, to which a constant-level tone of the same frequency was administered.

2.2. Participants

An unselected sample of 14 volunteers, most of whom were students at the University of Toronto, participated in the experiments in return for modest monetary compensation. This sample had a mean participant age of 21.9 ± 2.7 years (mean ± standard deviation). Seven females and seven males were tested; mean female age (22.3 ± 3.2 years) did not differ appreciably from mean male age (21.6 ± 2.3 years). Since this was an exploratory study on the existence of gender differences in auditory adaptation, female participants' phase of the menstrual cycle was not a controlled variable. Detailed instructions to participants and consent forms can be found in D'Alessandro (2008).

2.3. Apparatus

Stimuli were generated using a two-channel audiometer (Madsen Electronics, Micro 5, Oakville, Ontario) and were delivered to participants binaurally through supra-aural headphones (Madsen Electronics, TDH-39). The function of the audiometer was to deliver tones at a fixed auditory frequency for a set interval of time. The sound level delivered to each ear can be adjusted independently between threshold and 90 dB HL. The audiometer's phase was calibrated using a 2-channel digital real-time oscilloscope (Tektronic TDS210). The audiometer plus headphones were calibrated by measuring sound-pressure levels at the headphones using an artificial ear (Brüel and Kjær, Type 4152) and a sound level meter (Brüel and Kjær, Type 1613); the sound level meter was first calibrated with a sound level meter calibrator (Brüel and Kjær, Type 4230). There were no differences in calibration measurements made before and upon completion of the experiments.

Participants were tested individually, seated in the inner room of a double-walled, sound-attenuated chamber (Industrial Acoustics Company) located in the Institute of Biomaterials & Biomedical Engineering at the University of Toronto. A test frequency of 1000 Hz, which falls within the most physiologically sensitive region of the human auditory frequency range, was selected. Test tones were measured in dB SL (decibels sensation level), that is, with respect to each participant's individual threshold. Tones of 50 and 60 dB SL were chosen to maximize SDLB adaptation (which generally increases with increasing stimulus level (Jerger, 1957)) while minimizing recovery time needed after exposure to the stimulus (more intense stimuli generally require longer recovery times (Hirsh and Bilger, 1955)). The first phase of the experiment was designed to measure participants' thresholds.

2.4. Experimental design

Participants were required to adjust the sound level in the control ear from below threshold until the point of subjective equality (both tones sounded equally loud) was reached. The experiment consisted of three phases.

2.4.1. Phase 1

Participants were tested for their minimum threshold of hearing using a von Békésy (1947) adaptive tracking technique in combination with Levitt's (1971) 2-down 1-up stimulus presentation method. Once the threshold was located to within a 5 dB range, 2 dB decrements and 1 dB increments were used. The average of the three quietest tones the participants perceived, rounded to the nearest decibel, was recorded as their threshold value for that experimental session. The threshold values (measured in dB HL) for each participant were used to determine the 50 and 60 dB SL test tones to be delivered to the adapting ear. This first phase lasted approximately 8 min.

2.4.2. Phase 2

A participant's adapting ear (left ear) was exposed to a tone of constant level, either 50 or 60 dB SL. Immediately upon hearing the tone, participants were asked to increase the level of the tone in the control ear (right ear) from below threshold until the point of subjective equality was reached. They were instructed to use