GENDER DIFFERENCES IN AUDITORY ADAPTATION

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INTRODUCTION

The relationship between the physical intensity of a stimulus and the perception of that stimulus has been studied empirically since the 1860s. One example of such an empirically-derived relationship is Stevens' Power Law of Sensation ($\psi = k\varphi^n$). Stevens' Law relates the physical intensity (φ) of a stimulus to the perception of that stimulus (ψ). For the modality of audition, for example, loudness (ψ) is a function of the intensity (φ) of the auditory stimulus just as the saltiness of a solution (ψ) is a function of the saline concentration (φ) of that solution. The exponent (n) varies between modalities and is usually determined empirically.

In contrast to the empirically derived, individual sensory laws, the entropic theory of perception [1] was developed several decades ago as a conceptual unification of many of the empirical sensory laws; this unification gave a theoretical basis for sensory laws that until that time had only been examined empirically. As with Stevens' Law, entropy theory generalizes across modalities. It also utilizes many of the variables already familiar to us, (physical intensity, φ, the perceptual variable, ψ, and the exponent, n). Sensory phenomena occur in the time domain and entropy theory also includes time as a variable, allowing for a description of time-sensitive sensory phenomona such as auditory adaptation (the decrease in loudness perception to a sustained auditory stimulus). Many of the empirical sensory laws, including Stevens' Law, can be derived from entropy theory.

Previous studies [2] suggest that gender differences exist in the exponent (n) found in Stevens' Law governing loudness. Using entropy theory, a gender difference in the loudness exponent, present in Stevens' Law, allowed us to postulate the existence of gender differences in other sensory phenomena encompassed by entropy theory. We developed the following hypothesis: the amount of loudness adaptation measured in female and male listeners over the same time course will differ when pure tones of constant intensity and frequency are administered.

Extensive studies of both physiological and psychophysical differences in the female and male human auditory system have been reported [3], e.g. females exhibit greater amplitude and shorter latency in Wave V of the auditory brain-stem response and males experience greater permanent, noise-induced hearing loss. Since there have been no known reports of gender differences in auditory adaptation, an experimental protocol was developed to test this hypothesis.

One method of measuring the magnitude of adaptation is to apply a constant-intensity tone to the *adapting ear*, while retaining in silence the contralateral *control ear;* this method is termed *simultaneous dichotic loudness balance* (SDLB) (e.g. [4, 5]). At intervals after the start of the steady tone, the participant is required to adjust the intensity of the tone in the control ear until its loudness matches the loudness in the adapting ear. Adaptation is measured as the intensity difference, in decibels, at the control ear when the tone is initially presented to the adapting ear and at a later time point, t, for t equal to 1, 2, …, 6 min.

Preliminary test results suggest that gender differences exist in the rate and extent of auditory adaptation. This adaptation process can be hazardous since decreases in loudness perception allow prolonged exposure to potentially harmful sounds; this prolonged exposure has been identified as a common cause of hearing loss [6].

EXPERIMENTAL METHODS

Participants

Preliminary studies were conducted on 14 listeners who volunteered to participate in return for modest monetary compensation. Participants had no known auditory disease. Mean participant age was 21.9 years. Seven females and seven males were tested; mean female age (22.3 years) did not differ appreciably from mean male age (21.6 years). All experiments were conducted in accordance with an approved University of Toronto Ethics Protocol (#16187).

Apparatus

A Madsen, two-channel audiometer (Madsen Electronics, 0B70) was used to deliver auditory stimuli binaurally through headphones (Madsen Electronics, TDH-39). All experiments were carried out within a sound-attenuated booth located at the Institute of Biomaterials & Biomedical Engineering, University of Toronto. Prior to commencing the experimental studies, the audiometer was calibrated against recognized acoustic standards.

A test frequency of 1000 Hz, which falls within the most sensitive region in the human auditory frequency range, was selected. Practice tests were conducted at 50 dB SL, while experimental trials were conducted using a 60 dB SL stimulus.

Design and Procedure

Participants were required to adjust the *decibel intensity* in the control ear from below threshold until the *perceived loudness* in both ears is equal. That is, a decibel-intensity gives rise to a perceived loudness.

The experiment consisted of three phases. During the first phase, participants were tested for their minimal threshold of hearing. The experimenter administered brief (1.5 s) tones of very low decibel intensities to each ear, in turn. Participants signaled, by raising a hand, whether or not they heard the tone. To determine the threshold intensity, a modified von Békésy staircase method [7] was used **(Figure 1)** combined with Levitt's [8] 2-up 1-down stimulus presentation method.

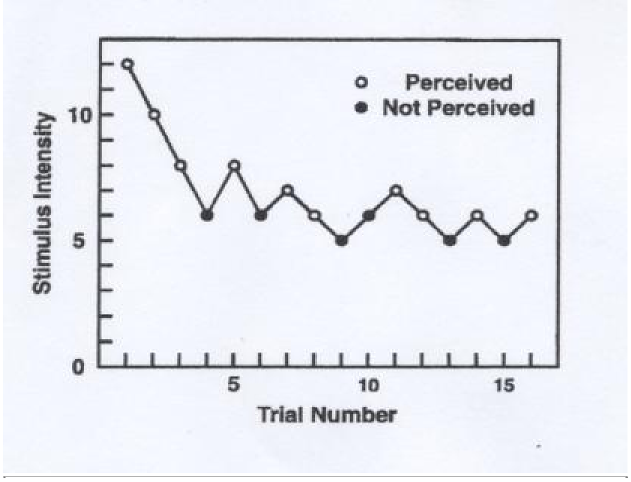

Figure 1: von Békésy staircase method for determining auditory threshold

The stimulus intensity began at a 20 dB supra-threshold intensity and was lowered in 10 dB steps until the participant was unable to perceive the tone. The stimulus was then increased in 5 dB increments until the participant signaled that the tone was again audible. Once the threshold was located to within a 5 dB range, the process was repeated with 2 dB decrements and 1 dB increments. This procedure continued until the participant's threshold value was approached. Threshold levels were subsequently used to determine the audiometric intensity needed to present the 50 dB SL practice tone and the 60 dB SL test tone. This first phase lasted approximately eight minutes.

During the second phase, a participant's adapting (left) ear was exposed to a 10 s tone of constant decibel intensity (**Figure 2**) and they were asked to adjust the loudness of the tone in the control (right) ear until it matched the loudness of the tone in the adapting ear. Studies on threshold recovery following pure tone stimulation [9] indicate that following 15 s of stimulation at 80 dB SL (1000 Hz), 45 s are required for auditory thresholds to return to pre-stimulation levels. Since tests were carried out at a maximum of 60 dB SL at 1000 Hz, a 50 s off-time was considered adequate for threshold recovery to occur following the 10 s matching period. This initial loudness matching procedure was repeated several times during a single trial to obtain a sufficient measure of a participant's average initial balance. This phase lasted 5 minutes.

During the third phase, the same 60 dB SL tone as used in Phase 2 was applied to the adapting ear for a duration of 6 min. Each minute on the minute, participants were again asked to adjust the decibel intensity of the tone in the control ear until they considered the loudness between both ears to be equal. Completion of Phases 2-3 constituted one *trial*; **Figure 2** pictorially depicts these two phases of the experimental procedure, which are similar to those conducted by other investigators [4, 5].

In order to ensure that participants were familiar with the experimental protocol, subsequent to threshold determination, a single practice trial of Phases 2 and 3 was carried out at 50 dB SL.

Each 1-hour experimental session consisted of an explanation of the experimental protocol, threshold determination (Phase 1), then one practice trial (50 dB SL, 1000 Hz) followed by two experimental trials (60 dB SL, 1000 Hz). A sufficient off-time of five minutes, as determined sufficient by Hirsch and Bilger [9], was allowed to elapse between successive trials to permit the ear to de-adapt, or return to pre-stimulation levels of sensitivity.

Each participant was asked to return for a second 1-hr experimental session to obtain a total of four trials at 60 dB SL. Participants completed no more than one 1-hr experimental session per day; no more than one month (31 days) elapsed between a participant's first and second visit.

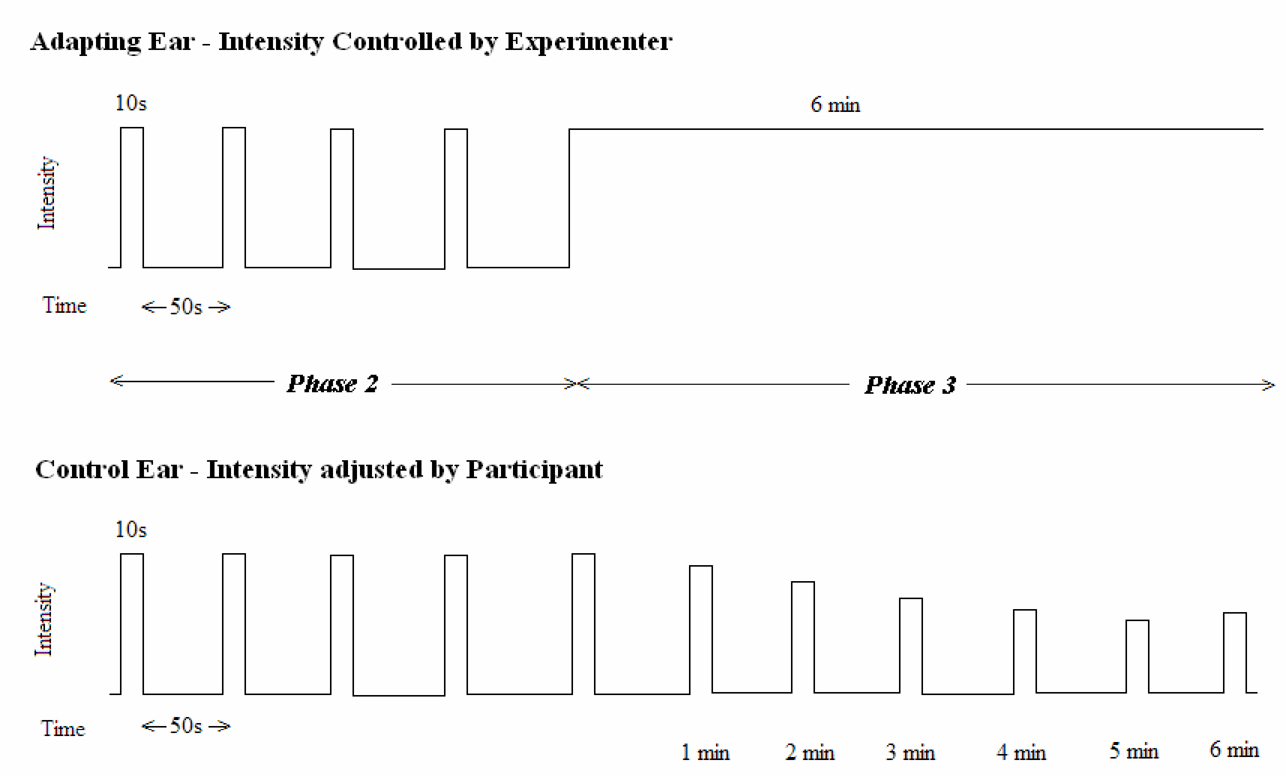

Figure 1: Pictorial Representation of Phases 2 and 3 of the Experimental Protocol.

Data Analysis

In this study, auditory adaptation for a given trial was taken to be the difference between the average of five initial balances (Phase 2) and each of the balances taken at 1 min, 2 min, …, 6 min (Phase 3). For example, decibels of adaptation at the t = 2 min sustained-tone time point equals intensity (in dB) at that 2 min point minus the average initial balance for that trial (also in dB).

RESULTS AND DISCUSSION

Average participant thresholds were approximately 0 dB HL in both the adapting and control ears (μ = -0.82, σ = 5.5 dB HL in the adapting ear; μ = -0.96, σ = 3.3 dB HL in the control ear). There were no notable differences between mean female and mean male thresholds in either the adapting or control ear (average female thresholds: -3.1 dB HL in the adapting ear, -1.4 dB HL in the control ear; average male thresholds: 1.4 dB HL in the adapting ear, -0.6 dB HL in the control ear.) Although measured thresholds differed between the two visits for each participant, threshold values tended to fall, on average, within 2.5 decibels of each other between visits; hence the 60 dB SL test tone presented to each participant was very close in intensity between successive visits.

Average initial balances to the 60 dB SL 1000 Hz test tone were also similar between both female and male participants (females: μ = -41.8, σ = 6.7 dB SL; males: μ = 44.1, σ = 10.0 dB SL). However, the amount of adaptation observed after 1 min, 2 min, …, 6 min of sustained auditory stimulation differed between genders, with females exhibiting greater auditory adaptation than males. Experimental results are listed in **Table 1**. A two-factor ANOVA with gender as between subjects variable and time as within subjects variable revealed a statistically significant main effect of gender ($F_{(1,\ 84)} = 20.15$; $p < 0.001$) on adaptation. As expected, there was a significant effect of time on adaptation ($F_{(6,\ 84)} = 2.58$; $p < 0.05$); that, is, auditory adaptation increases with time. There were no interaction effects between gender and time ($F_{(6,\ 84)} = 0.80$; $p > 0.05$).

There are both advantages and disadvantages to employing the modified SDLB experimental protocol. An advantage is that the SDLB method does *not* employ magnitude estimates, or the assigning of numbers to sensation, hence providing a less subjective measure of loudness adaptation.

Table 1: Average adaptation, in decibels, collected from four trials of the SDLB technique described in Experimental Methods. Results are averaged from seven female and seven male participants for a 1000 Hz, 60 dB SL tone.

Time	**Decibels of Adaptation**	
	Females	***Males***
1 min	- 4.3	- 0.4
2 min	- 9.3	- 2.7
3 min	- 10.9	- 1.3
4 min	- 9.7	- 3.4
5 min	- 11.1	- 3.6
6 min	- 11.7	- 3.6

There are also disadvantages to this SDLB method of testing, including interaction effects between ears confounding adaptation measurements. However, irrespective of an interactive mechanism, the overall results were observed consistently. Additionally, some adaptation occurs during the initial 10 s balance. However, minimizing the adaptation that occurs during this time, for example, by using briefer pulses, would only serve to *increase* the observed measure of adaptation. Notwithstanding these disadvantages, the method described herein is taken as a valid means of quantifying auditory adaptation [4, 5]. Mathematical analysis follows that found in [1, p.189].

CONCLUSIONS

Although gender differences in the human auditory system have been studied extensively [3], no report of gender differences in loudness perception has been found. A modified SDLB technique (c.f. [4, 5]) was developed to measure loudness adaptation between genders. A participant's estimate of initial loudness to a 60 dB SL, 1000 Hz tone was clearly established. Then, the (same) experimental stimulus was applied for a duration of 6 min. Auditory adaptation was taken as the difference between average initial loudness balances and balances made following sustained experimental tones (1, 2, …, 6 min). This preliminary study suggests that female adaptation exceeds male adaptation, an observation that supports our original hypothesis. Recovery time, or the time needed for the ear to de-adapt, both between stimuli and between successive trials, was carefully monitored and integrated into the experimental protocol.

The Canadian Association of Speech Language Pathologists and Audiologists reports [10] that in young adults, the hearing acuity of males and females differs by approximately 3-5 dB. The results of the current study suggest a possible avenue by which this difference could occur. Auditory adaptation results in a decrease in one's perception of the loudness of a tone; differential rates of adaptation allow people to remain exposed to harmful sounds for differing lengths of time, leading to differences in hearing acuity. Additionally, these results are relevant in advising both manufacturers of personal auditory devices and federal policy-makers who determine occupational noise exposure limits designed to protect the population against premature hearing loss.

ACKNOWLEDGEMENTS

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REFERENCES

[1] K. H. Norwich, *Information, Sensation and Perception*, Academic Press, San Diego, CA, 1993.

[2] E. Sagi, L. M. D'Alessandro, and K. H. Norwich, "Identification variability as a measure of loudness: an application to gender differences," *accepted to Canadian Journal of Experimental Psychology*, 2007.

[3] D. McFadden, "Sex differences in the auditory system," *Developmental Neuropsychology*, vol. 14, pp. 261-298.

[4] J. D. Hood, "Studies in auditory fatigue and adaptation," *Acta Oto-laryngologica Suppl.,* vol. 92, pp. 1-57, 1950.

[5] E. M. Weiler, M. Loeb, and E. A. Alluisi, "Auditory Adaptation and its relationship to a model for loudness," *Journal of the Acoustical Society of America,* vol. 51, pp. 638-643, 1972.

[6] Dalton, D. S. Cruickshanks, K. J., Wiley, T. L., Klein, B. E. K., Klein, R. and Tweed, T. S. (2001). Association of leisure-time noise exposure and hearing loss, *Audiology*, vol. 40, pp. 1-9.

[7] G. von Békésy, "A new audiometer," *Acta Oto-laryngologica,* vol. 35, pp. 411-422, 1947.

[8] H. Levitt, "Transformed up-down methods in psychoacoustics," *Journal of the Acoustical Society of America,* vol. 49, pp. 467-477, 1971.

[9] I. J. Hirsch and R. C. Bilger, "Auditory threshold recovery after exposure to pure tones," *Journal of the Acoustical Society of America,* vol. 27, pp. 1186-1194, 1959.

[10] Canadian Association of Speech Language Pathologists and Audiologists, CASLPA. "Fact Sheet: Noise-Induced hearing Loss," 2006.