defining (R) tones, at random intervals between the R tones. The Rhythm A and B sequences now sounded like random temporal patterns of tone *f*, and any detection of the embedded rhythm was impossible. To make it easy again, we caused the distracter tones to have a different timbre from the R tones. We did this by adding “flanker” tones, more or less synchronous with the distracter tones, and above and below the latter in frequency. If the flankers fused perceptually with the distracters, the fused tones now had a timbre distinct from the pure-tone quality of the R tones and formed a separate complex-tone stream. Now the original R tones could be heard again as a stream of pure tones. This recovery of discrimination depends on the timbre caused by the fusion of the distractor tones with their and flanker tones; so the ability to discriminate can be used as a measure of the fusion of these tones. Using this method, we found that the most important factors relating the flankers and distractors, at least in the case of the short tones that we used, was how synchronous their onsets were and the duration of their temporal overlap. Harmonic relations between the partials had some influence, but only an extreme degree of spatial separation (dichotic presentation) affected fusion (Turgeon, Bregman & Roberts, 2005).

These examples illustrate the close relation between ASA and rhythm. Rhythms are formed out of units, linked sequentially into auditory stream streams. The processes that form both units and streams are general ones that operate with all sounds. For this reason, the general principles of ASA can help us predict the formation of rhythms and rhythms can be used to study ASA.

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OBTAINING THE LOUDNESS EXPONENT FROM BINAURAL AUDITORY ADAPTATION DATA

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Abstract

The loudness of a stimulus, L, is related to the intensity of that stimulus,φ*, by Stevens' Power Law,* $L = K\varphi^{n}$*, where K is an arbitrary scaling constant and n is the loudness exponent. The exponent, n, has been measured extensively by psychophysicists usually by magnitude estimation. We devised a new method for obtaining n from experiments using the SDLB (simultaneous dichotic loudness balance) technique. That is, we presented a 6-min continuous tone to a participant's adapting ear. At 1-min intervals, participants adjusted the intensity of the tone in the contralateral control ear until both tones sounded equally loud. We used the control ear, which was otherwise retained in silence, to measure the progressive adaptation in the adapting ear. The value of n may be estimated by dividing the number of decibels of adaptation at 6 minutes (near equilibrium) by the intensity of the continuous tone in dB SL.*

The loudness exponent, *n*, defines the relationship between the intensity of a pure tone (measured, for example, in watt.cm^{-2}) and the loudness of the tone (measured sometimes in units of *sones*, but in all cases dimension-free). In this paper we shall express intensity as a dimensionless ratio, $\varphi / \varphi_{\text{thresh}}$, where φ_{thresh} is the threshold of the listener. $10 \log_{10} (\varphi/\varphi_{\text{thresh}})$ expresses the intensity of a tone as *sensation level* or SL. The equation that explicitly connects loudness with intensity is the power law of sensation, developed by S. S. Stevens:

$$L = k(\varphi/\varphi_{\text{thresh}})^{n}$$

In this equation, *k* is a scaling constant, greater than zero but otherwise arbitrary, that determines the magnitude of *L*. The exponent, *n*, is of paramount importance in psychoacoustics. This exponent compresses the physical variable, intensity ($\varphi/\varphi_{\text{thresh}}$), which extends over a range of about 9 decades in everyday life into a range of only about 3 decades for the psychophysical variable, loudness, *L*. The value of *L* is commonly measured by the method of magnitude estimation. Using this technique, the value of *n* has been found to be about 0.3 for all auditory frequencies between about 400 to 10,000 Hz

It had generally been held that there was no gender difference in the values of *n.* However, research conducted by our group (Sagi, D’Alessandro and Norwich, 2007) suggests that the loudness exponent for females exceeds that for males. In Sagi *et al*. (2007), we introduced techniques for measuring the *relative* values of *n* (females vis-à-vis males) without using classical subjective assessment such as magnitude estimation. Participants, who had been appropriately trained, were required to identify the dB intensity of unknown tones. From the *errors* made by these participants we were able to estimate relative values of *n* over a range of frequencies (125 to 8000 Hz). When measured by this technique, the mean value for *n* over all auditory frequencies we tested was 0.3053 for females and 0.2218 for males. These observed differences in *n* between genders were statistically significant. In the present study, we examine another method of quantifying the loudness exponent, *n*, using an independent set of experiments: studies on auditory adaptation.

Methods

We measured loudness adaptation in a group of 14 participants, 7 male and 7 female, with mean age of about 22 years. Loudness adaptation is the decrease in loudness of a steady tone with increasing duration of the tone. There are two methods by which adaptation can be measured. Magnitude estimation can be used to trace the course of loudness adaptation when a steady tone is applied to one ear for a protracted time interval. However, we opted in favor of the *simultaneous dichotic loudness balance*, or SDLB. The elements of this technique were described by von Békésy in (1929, 1960). However, it was named and developed by Hood (1950). It essentially uses one ear, the *control ear*, retained in silence, to monitor the level of adaptation in the other ear (the *adapting ear*) to which a constant-intensity tone is administered.

Experiments were conducted in a sound-attenuated booth. Constant intensity tones were generated by an audiometer (Madsen Electronics, *Micro 5*) and administered to participants binaurally by means of headphones. Loudness thresholds were first determined in each participant using a Békésy staircase method. Thereafter, all sound intensity values were measured as dB SL, relative to each participant's own threshold. A steady tone of 50 dB SL (1000 Hz) was delivered to the adapting ear, and maintained for 370 s. After intervals of 0, 60, 120, 180, 240, 300 and 360 seconds, the participant was required to manually adjust the level of sound in the *control ear* until the tones in each ear were equally loud. This loudness balance was completed in 10 s, after which the control ear was returned to silence and maintained in that state for 50s. After this 50s interval, participants repeated their loudness balance. In this way, they provided values for matching intensities, $\varphi(t) = \varphi(10)$, $\varphi(70)$, $\varphi(130)$ … $\varphi(370)$ progressively. These values of φ will be known as *intensities of adaptation.* Within a 1-h experimental session, participants made this series of loudness balances with two different tone intensities administered to the adapting ear: once with 50 dB SL and twice with 60 dB SL.

Observations

There are two ways in which one can report the magnitude of adaptation:

(i) Subtract the intensities of adaptation from the intensity of the applied tone to obtain *absolute adaptation*. In this way we calculate:

Magnitude of adaptation to 50 dB tone =

$$[50 - 50],\quad [50 - \varphi(10)_{\text{dB}}], [50 - \varphi(70)_{\text{dB}}], \ldots, [50 - \varphi(370)_{\text{dB}}],$$

and, Magnitude of adaptation to 60 dB tone =

$$[60 - 60],\quad [60 - \varphi(10)_{\text{dB}}], [60 - \varphi(70)_{\text{dB}}], \ldots, [60 - \varphi(370)_{\text{dB}}].$$

(ii) Subtract the intensities of adaptation from the intensity of the 10-second intensity of adaptation to obtain a measure of *relative adaptation*. In this way we calculate for each of 50 and 60 dB adapting tones

Magnitude of adaptation = $[\varphi(10)], - \varphi(10)], [\varphi(10)], - \varphi(70)] \ldots [\varphi(10)], - \varphi(370)]$.

Representative graphs showing these data (50 dB absolute adaptation and 60 dB relative adaptation) are given in Figures 1 and 2, respectively. More complete tabulation of the data is given in the M.Sc. thesis by D'Alessandro (2008).

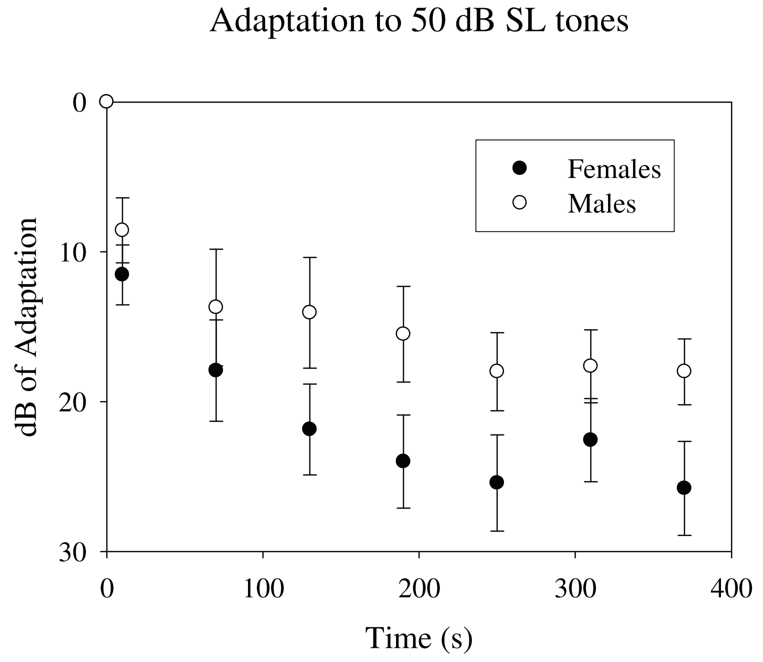

Figure 1: Absolute Adaptation. dB of adaptation (calculated with respect to the 50 dB reference intensity) versus time averaged over all 7 female and all 7 male participants. Data points are superimposed at 0 s.

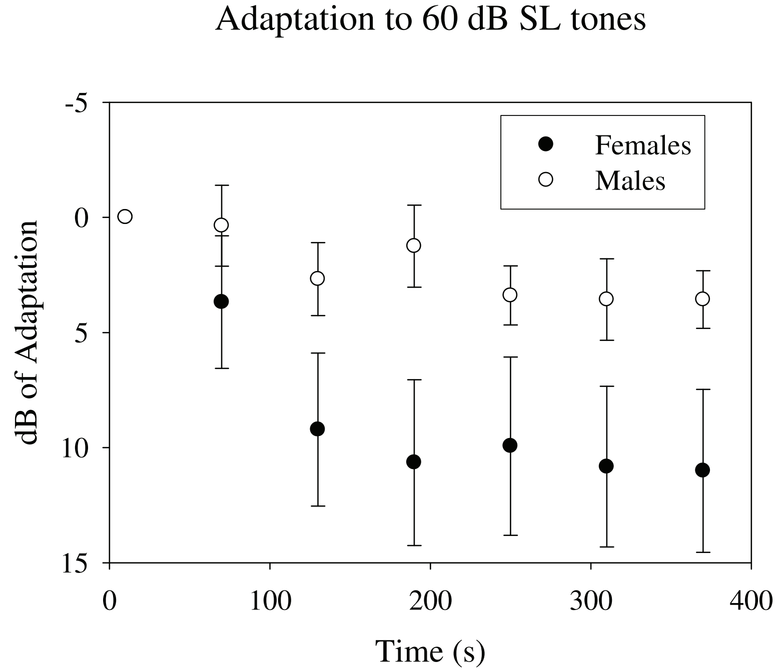

Figure 2: Relative Adaptation, in dB, calculated with respect to the 10 s reference intensity versus time averaged over all 7 female and all 7 male participants. Data points are superimposed at 10 s.

Analysis

Certain features of the data are immediately apparent from the figures. In both the absolute and relative modes of calculation, females adapt to a greater extent than males of the same age. The difference in the magnitude of adaptation between females and males at the final (370 s) time point is statistically significant ($p < 0.05$) except for relative adaptation at 50 dB. Although not reported by earlier researchers, the variable, $\varphi(t)$, which measures the extent of adaptation, seems to oscillate towards an asymptote, rather than decline monotonically. There are several reasons to believe that these are true oscillations and not noise in the data. Perhaps the most compelling is that when a given participant was tested on two different days, often separated by one week or more, he or she would replicate their initial loudness balances quite closely.

The theory underlying the calculation of the value of the exponent, n, from adaptation data is under development. For absolute adaptation we estimate the value of n from the ratio of maximum adaptation in decibels to the magnitude of the applied tone in decibels. Thus, for example, from Figure 1 it may be seen that maximum absolute adaptation for males is about 18 dB in response to a 50 dB adapting tone. The value of n may then be estimated as 18/50 = 0.36. The method was modified slightly for calculations from relative adaptation data. Calculations are summarized in Table 1.

Discussion

We observe that at each intensity and for both absolute and relative adaptation the mean values of n for females again exceed those for males. This result is in consonance with our previous studies on n (see above) [1].

There were a number of papers published offering a detailed study of the SDLB technique used here. We selected two studies whose experimental protocols were most similar to our own; they reported data from test tones ranging from 30 to 90 dB, and sometimes over many auditory frequencies. These were papers by Jerger (1957) and Weiler *et al.* (1972).

Table 1: n-values calculated from our model using adaptation data from the present study

	***n*-values (1000 Hz)**					
	Absolute (0 s reference)			***Relative (10 s reference)***		
	Females	***Males***	***Avg.***	***Females***	***Males***	***Avg.***
50 dB SL	0.52	0.36	0.44	0.37	0.26	0.32
60 dB SL	0.49	0.32	0.41	0.26	0.09	0.17
Avg. over gender	0.50	0.34	0.42	0.32	0.18	0.25

Table 2: Loudness exponents from data of Jerger (1957) and Weiler *et al.*, (1972)

	***n*-values (1000Hz)**	
dB tone	***Jerger***	***Weiler* et al.**
30	0.37	-
40	0.33	0.31
50	0.34	0.30
60	0.36	0.34
70	0.29	0.29
80	0.31	0.27
90	0.30	-
Avg.	0.33	0.30
St. Dev.	0.028	0.025

Jerger measured auditory adaptation at 7 frequencies and 7 intensities. At 1000 Hz, he measured adaptation at intensities ranging from 30 to 90 dB SPL, inclusive, in 10 dB SPL increments (i.e., at 30, 40, 50, 60, 70, 80, and 90 dB SPL). Many of the characteristics of his SDLB experiment were similar to ours. He employed a 15 s on-time and 45 s off-time (cf. 10 s on-time, 50 s off-time used presently). The adapting stimulus was 5 min long (cf. 6 min in our study). His participants were instructed to use midplane localizations (adjusting the intensity of the sound until is seems localized in the midplane), instead of loudness balances; however Weiler and Blackmond (1973, p. 102) report that the 2 techniques give similar adaptation results. Decibels of adaptation were calculated with respect to a 15 s point.

Similarly, Weiler *et al.* report dB of adaptation − also measured using the SDLB technique − for 5 stimulus levels in the range 40-80 dB SPL at 1000 Hz; that is, at 40, 50, 60, 70, and 80 dB SPL. His group used 10 s on-times and 50 s off-times. The adapting stimulus was 7 min long. Decibels of adaptation were calculated with respect to a 10 s point.

The value of the exponent, n, is calculated in the same manner as used on our own data, however, not all the required data were provided explicitly in these papers. For example, the matching intensity for the 10s (or 15 s) points used in the calculation of n from relative adaptation is not given. SPL rather than SL was used in some cases. The reported results are correspondingly approximate. The calculated values for n at various intensities are shown in Table 2 from the data of Jerger and Weiler *et al.*

Summary

A study of apparent adaptation using the SDLB technique revealed that young women adapt to steady tones to a greater extent than men of the same age. The adaptation data can be used to estimate values for the power function exponent, n, that are usually measured by magnitude estimation. The calculated values of n reveal that n is significantly larger in females than in males, a result that confirms our earlier study. The same technique of calculation applied to the data of other researchers produced nominal values for n as well.

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AUDITORY FREQUENCY FOCUSING IS EXTREMELY RAPID

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Abstract

Auditory threshold is 3 to 5 dB higher when signal frequency changes from trial to trial than when the same on every trial. This threshold increase can be avoided by presenting a weak cue at the same frequency as the signal at the beginning of each trial. To achieve this improvement, Scharf, Reeves, and Suciu (2007) showed that the cue onset must precede the signal onset by at least 200 ms. Threshold increased as signal delay decreased from 352 to 82 ms. It was unclear whether poorer detection at shorter delays was caused by sluggishness in focusing on the correct frequency or by interference from the temporally proximate cue. We now show that the threshold at delays at least as short as 52 ms can be ascribed primarily if not entirely to interference. The implication is that selective frequency focusing is very rapid.

Weak sounds may be detected more easily when preceded by a cue that informs the listener about the frequency content of the following signal (e.g. Green, 1961). Recently, we (Scharf, Reeves, and Suciu, 2007) measured the decrease in threshold as a function of the delay of the onset of a brief signal relative to the onset of a preceding cue. We showed that an ipsilateral cue presented only some 82 ms before a signal of uncertain frequency helped detection but less so than the same cue presented 352 ms before the signal. The improvement in detection decreased monotonically as the signal delay went from 352 to 82 ms. Although we ascribed, tentatively, the decline in detection primarily to the listeners' inability to focus attention rapidly on the target frequency, we indicated the possibility that a cue presented shortly before a signal could interfere with signal processing. To evaluate this possibility, we have now measured detection with *frequency certainty* in the presence of ipsilateral cues. In frequency certainty, i.e. with the signal frequency known before the beginning of a trial, it has been shown that introducing a cue well ahead of signal onset does not improve detection (e.g. Gilliom and Mills, 1976; Scharf, Quigley, Aoki, Peachey, and Reeves, 1987). Accordingly, under the conditions of the present experiment, any increase in threshold with decreasing signal delay would not reflect sluggish frequency focusing; it would reflect some kind of interference by the cue with detection.

Method

All tones, both signals and cues, were 40 ms bursts. The duration of 40 ms does not include the cosine squared rise time of 7 ms and fall time of 5.3 ms; the equivalent rectangular duration equaled 46 ms. Cues and signals were always presented to the left ear. All tones were presented against a continuous background of broadband noise set to a low spectrum level of 12.44 dB. At such a relatively low noise level, Botte (1995) has shown that the attention band is narrower than at higher levels and so would help counter the widening of the attention band with brief signals (Wright and Dai, 1994). The noise was presented binaurally and was in phase at the two earphones.