Gender differences in optimal listening levels and loudness perception

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ABSTRACT

The experimental measurement of optimal listening levels for various sounds, such as music, has shown that male participants tend to adjust their optimal listening levels higher than their did female counterparts do. This gender difference for reproduced sounds might be affected by the gender difference in loudness perception. To examine gender differences in loudness perception, we conducted rating experiments of the loudness of various sounds. These experiments revealed that female participants assigned higher loudness scores than did males for the same sound. We also found that the difference in optimal loudness between male and female participants was approximately equal to their difference in optimal listening levels. To confirm the factors affecting the gender difference in loudness perception, rating experiments of loudness were conducted using an interval scale and a ratio scale. A gender difference was observed regardless of the range of sound pressure levels or the number of steps in the verbal interval scale. However, this difference was not clearly observed when a ratio scale, i.e., magnitude estimation, was used for evaluation of loudness. Gender differences in loudness judgments may actually reflect differences in the use of verbal expression rather than differences in perception of intensity.

Keywords: Gender Difference, Optimal Listening Levels, Loudness
I-INEC Classification of Subjects Number (s): 63.1

1. INTRODUCTION

Previous studies have reported a gender difference in optimal listening levels (OLLs) of music: men adjust their OLLs higher than do women [1-3]. Gender differences in the auditory system, such as less efferent inhibition [4] and higher sensitivity of hearing in women than in men [5], have also been reported. In addition, Torre found that men required a higher sound pressure level to perceive the loudness of reproduced sounds as loud than did women [6]. On the basis of those reports, we hypothesized a gender difference in loudness perception wherein women would perceive sounds as being louder than men would for the same sound pressure level. This difference in perceived loudness might be a factor affecting the gender difference in OLL. To confirm this assumption, we systematically examined gender differences in OLLs, and in loudness perception, and their relationship.

We previously measured OLLs of various sounds and revealed that the gender difference was observed regardless of the type of sound, except for natural environmental sounds [7-11]. Rating experiments on the perceived loudness of sounds have also shown a gender difference: for the same sound pressure level, male participants tend to rate sounds as less lound than do female participants [8,10,12]. This difference did not depend on type of sound, frequency region or ranges of sound pressure level, or on the evaluation scale employed. The gender difference for the optimal loudness of sound was almost equivalent to that for OLL [13]. The difference in loudness perception could be a factor affecting the difference in OLLs. However, the gender difference in loudness perception was not clearly observed when a ratio scale was used for evaluation of loudness, although the power

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exponent α in Stevens' power law was slightly larger for female than that for male participants [12].

In this paper, we outline our studies on gender differences in OLLs and loudness perception.

2. GENDER DIFFERENCE IN OPTIMAL LISTENING LEVELS (OLLS)

2.1 Gender Difference in OLLs of Music

The participants were 14 students (7 men and 7 women), aged 21 to 30 years old. The sound stimuli were six music excerpts (each approximately 90 s in duration). The participants listened to the stimuli via headphones and adjusted the sound volume of an iPod to OLLs for enjoying each tune. Equivalent continuous A-weighted sound pressure level (L_{Aeq}) of each tune at OLL was measured using an artificial ear and a sound level meter.

The results of the measurement are shown in Figure 1. The gender effect was statistically significant ($F[11,72] = 13.2$, $p < 0.05$) by two-way ANOVA. The effect of the stimulus and the interaction between gender and stimulus were not statistically significant. Male participants tended to adjust OLLs higher than did female participants [7].

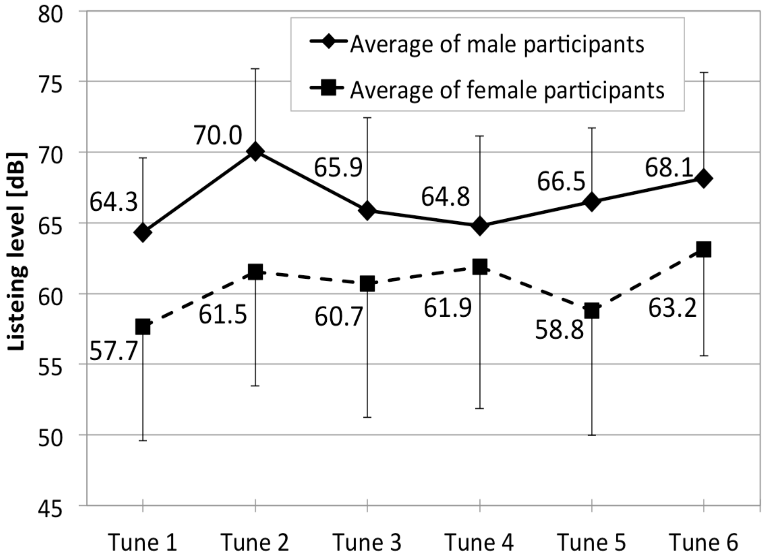

Figure 1 – Average OLL of music for male and female participants.

2.2 Comparison Between Gender Difference in OLLs and Intra-individual Variations

In the research described in the previous section, the OLL was measured only once for each stimulus. If we adjusted the OLL several times, the level might be differ, even within the same tune. The difference among the adjustment levels of each participant's trials for each stimulus was compared with the difference of the average adjustment level between the male and female participants. To enable discussion of such differences, the OLL for each stimulus was measured five times. The experiment comprised five sessions, and four sound stimuli were reproduced randomly in each session. To avoid the possibility that the OLL adjusted in previous sessions would influence the current adjustment, the headphone amplifier and the participants' hands were covered by a box. The participants were 14 students of Kyushu University (7 men and 7 women), aged 21 to 31 years old.

The difference in OLLs within a session was called "intra-individual variation," and was defined as the difference between the maximum and minimum OLLs in each session. The upper limits of 95% confidence intervals for intra-individual variation were smaller than the differences in OLLs between the male and female participants for all stimuli. These results showed that the intra-individual variation in OLLs caused by making multiple adjustments was smaller than the gender difference. In addition, a two-way ANOVA revealed that the effect of gender was statistically significant ($F[1,272] = 177.88$, $p < 0.01$); male participants adjusted their OLLs higher than did female participants. The experimental results therefore confirmed the existence of the difference in OLLs between men and women. This difference was not coincidental [8].

2.3 Effects of Acoustic Characteristics on the Gender Difference in OLLs

To clarify the effects of acoustic characteristics of music on the gender difference in OLLs, experiment on OLLs was conducted with music whose acoustic spectrum was modified. In the low-frequency boost condition, the region between 63 Hz and 125 Hz was enhanced. In the high-frequency boost condition, the region between 2 kHz and 16 kHz was enhanced. The experimental procedure was the same as described in section 2.1.

Regardless of which frequency band was enhanced, the results were similar to those in previous studies [7,8]: male participants selected higher OLLs than did female participants [9]. No effect was observed of acoustic characteristics of the music on the gender difference.

2.4 Effects of Background Noiseon the Gender Difference in OLLs

It is well known that the listening levels of music become higher when background noise is present [14]. To clarify the effects of background noise on the gender difference in OLLs, optimal levels were measured in a noisy condition. Traffic noise of 63 dB and 73 dB were reproduced 2 m in front of participants for 2 minutes while participants adjusted music to OLLs. Although the optimal levels became higher as the noise level increased, the gender difference in OLL was observed in both noise level conditions: as in the quiet condition, male participants selected higher OLLs than did female participants [10].

2.5 Gender Difference in OLLs of Ambient Music

In the previous sections, OLLs were measured using a portable audio player to present the active music-listening conditions. In this section, OLLs were measured in a passive music-listening condition with ambient music. The stimuli were music samples typically used as ambient music in restaurants and amusement parks, and were reproduced from a loudspeaker 2 m in front of the participants. Again, the gender difference in OLLs was observed, with male participants choosing higher OLLs [9].

2.6 Gender Difference in OLLs of Environmental Sounds

To investifate potential effects of type of sound on the gender difference, OLLs of environmental sounds such as warning sounds for train departure, public announcements and natural environmental sounds were measured. The OLL of warning sounds for train departure and public announcements was statistically different between male and female participants [11]. The male participants again selected higher sound pressure levels than did their female counterparts. However, the gender difference in OLLs of natural environmental sounds was not observed [7]. The OLLs of natural environmental sound were not determined by loudness preferences, but adjusted according to the memory of the sounds.

3. GENDER DIFFERENCES IN LOUDNESS RATING

For various kinds of sounds, the OLL for the male participants was consistently higher than that for the female participants, expect where natural environmental sounds were concerned. Previous studies have revealed less efferent inhibition [4] and higher sensitivity of hearing in women than in men [5]. In addition, Torre reported that male participants require a higher sound pressure level to perceive the loudness of reproduced sounds as loud than female participants do [6]. On the basis of those reports, we hypothesized a difference in loudness perception between men and women, with the latter perceiveing the same sounds as louder. If perceived loudness for sound of the same sound pressure level was different between male and female participants, the OLL of the males would be perceived as 'louder' by females. Therefore, female participants would adjust the OLL lower than would male participants. The difference of loudness perception between male and female perticipants was implicated as a factor affecting the difference in the OLLs. To confirm this assumption, a rating experiment on perceived loudness of various sounds was conducted.

3.1 Music

The six music excerpts described in section 2.1 were used as stimuli. Sound pressure level of each stimulus was set to the average level of OLL of music for the male and female participants' data obtained in section 2.1 (Average condition), +5 dB from the average condition (+5 dB condition) and −5 dB from the average condition (−5 dB condition). After listening to each stimulus, the participants rated its loudness using a seven-step rating scale from 1 to 7 (1: Very soft; 2: Soft; 3: Somewhat soft; 4: Optimal; 5: Slightly loud; 6: Loud; 7: Very loud). In all conditions, the average values of ratings of female participants were larger than those of the male participants: the female participants tended to give higher loudness scores for the same sounds [7]. The difference in average ratings between the male and female participants was statistically significant.

3.2 Broadband Noise

The sound stimulus was pink noise. The duration of presentations was 15 s, and sound pressure levels were adjusted to 55 dB, 60 dB, 65 dB, 70 dB and 75 dB. These sound pressure levels were determined from the distribution range of the OLLs of music obtained in section 2.1. The stimuli were reproduced from a loudspeaker positioned 2 m in front of the participants. The participants rated the loudness of the stimuli using the seven-step rating scale describe in section 3.1, expect that the response associated with the value 4 was replaced by “Neither soft nor loud.”

The average evaluated values on loudness and their standard deviations for each stimulus are shown in Figure 2. The female participants tended to assign higher loudness scores than did the male participants for stimuli of the same sound pressure level. The Friedman test was applied to the obtained data. The effects of sound pressure level and of gender were statistically significant (χ^2 = 34.281, $p < 0.01$ for sound pressure level; χ^2 = 4.597, $p < 0.05$ for gender). This result confirmed that the female participants perceived sounds of the same sound pressure level as louder than the male participants did [8].

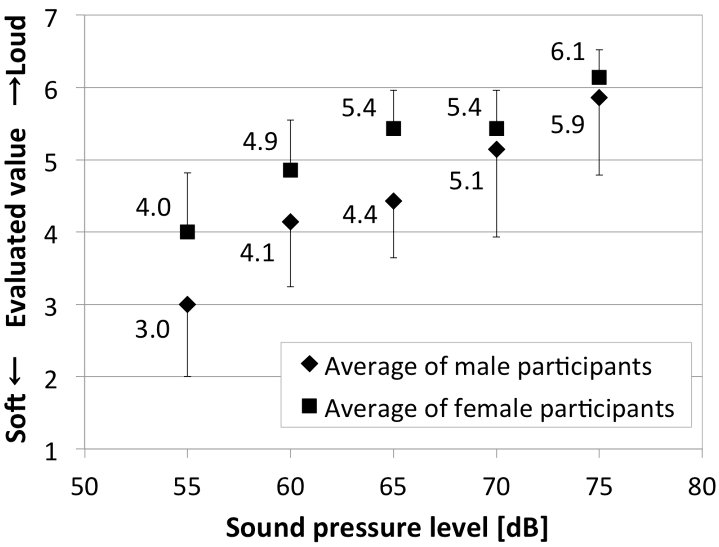

Figure 2 – Average optimal listening level of music for male and female participants.

3.3 Narrowband Noise

The 1/3-octave band noises of seven center frequencies (125 Hz, 250 Hz, 500 Hz, 1 kHz, 2 kHz, 4 kHz and 8 kHz) were used as stimuli. The duration and sound pressure levels of the stimuli and the experimental procedure were the same as those described in section 3.2. As was the case with music and broadband noise, female participants tended to select higher loudness scores than did male participants when the stimuli were at the same sound pressure level, regardless of the center frequency. Because of independency of frequency region in gender difference in loudness perception, the gender difference in OLLs of music did not seem to be affected by spectral modification [8].

3.4 Natural Environmental Sounds

From the findings in the previous section, one could speculate that the gender difference in loudness perception might cause the gender difference in OLL. However, the gender difference in OLL was not observed for natural environmental sounds (section 2.6). To further investigate the gender difference in loudness perception for natural environmental sounds, a rating experiment was conducted similar to the previous ones.

The four natural environmental sounds from the experiment described in section 2.6 were used as the sound stimuli. The sound pressure levels of each stimulus were set to −5 dB, average, +5 dB, +10 dB and +15 dB conditions in the same way as sescribed for the musical stimuli in section 3.1. The participants rated the loudness of the stimuli using the same seven-step ratingscale (with evaluation value 4 labeld “optimal”). The female participants again tended to produce higher loudness ratings than did the male participants for stimuli of the same sound pressure level [7]. This finding supported our interpretation of the experimental results for natural environmental sounds in section 2.6: the OLL of natural environmental sounds was adjusted according to the memory of these sounds, and as a result, no gender difference was observed.

3.5 Ratings of Loudness Using a Wider Range of Scale and Stimuli

To confirm and extend findings from the perceived loudness experiments described in previous sections, a rating experiment was performed with a wider range of sound stimuli and finer categories of an interval scale of loudness. This experiment used pink noise and 1/3-octave band noises with seven center frequencies (125 Hz, 250 Hz, 500 Hz, 1kHz, 2 kHz, 4 kHz and 8 kHz) at sound pressure levels of 40 dB to 75 dB in 5-dB steps (L_{Aeq}: equivalent continuous A-weighted sound pressure level). The sounds were presented from a loudspeaker positioned 2 m in front of the participants. The participants used a 10-step scale from 0 to 9 (0: Barely audible; 1: Marginally audible; 2: Very soft; 3: Soft; 4: Somewhat soft; 5: Neither soft nor loud; 6: Slightly loud; 7: Loud; 8: Very loud; 9: Unbearably loud) for rating perceived loudness.

The average evaluated values of loudness and their standard deviations for male and female participants under the condition of pink noise are shown in Figure 3. The results for 1/3-octave band noises were similar to those in the figure: female participants tended to give higher loudness scores than did male participants for pink noise of the same sound pressure level. The difference in loudness perception between male and female participants was observed regardless of the range of sound pressure levels or the number of steps in the interval scale used for evaluation. As was the case in the previous sections, female participants rated the same sounds as louder than did the male participants [12].

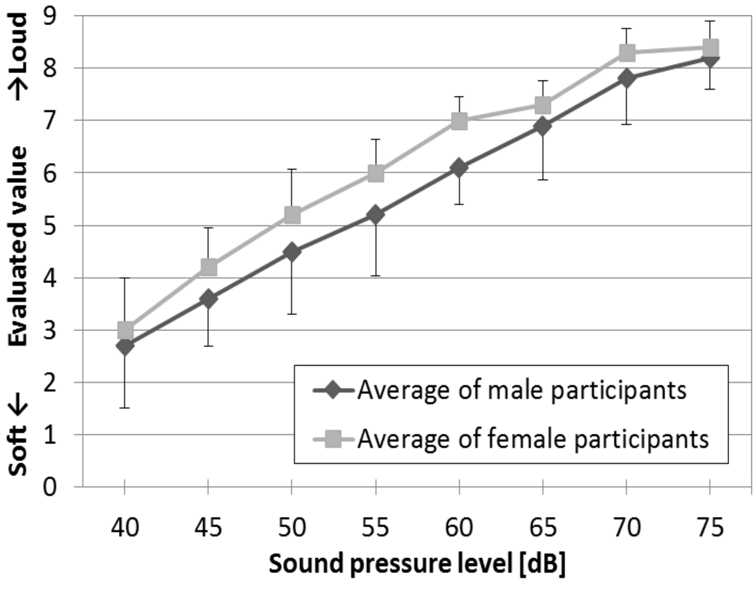

Figure 3 – Average evaluated loudness of pink noise for male and female participants. Error bars represent standard deviations.

3.6 Method of Adjustment to Achieve Soft and Loud Sounds

The experiments of the previous sections demonstrated a robust effect of female participants rating sounds at the same sound pressure level as louder than did male participants. A possible explanation for this effect is that the criteria for men and women’s perceiving of sounds as “soft” or “loud” might be different. If this explanation holds, women would be expected to judge sound of lower sound pressure levels as "soft" and "loud" than men would. To confirm this assumption, an experiment was conducted using the method of adjustment to measure the limits of sound pressure levels perceived as "soft" or "loud."

The pink noise described in section 3.5 was used as the stimulus. The sounds were presented from a loudspeaker positioned 2 m in front of the participants, as in section 3.5. While listening to the stimulus, the participants dragged a mouse to adjust the sound pressure level up or down to reach the limit that they perceived as soft or loud, depending on the condition: the limit of the sound pressure level perceived as "soft" means the highest sound pressure level of sound that the participant would categorize as soft; "loud" means the lowest sound pressure level categorized as loud. The participants received no information about sound pressure levels of the adjusted stimuli. The adjusted sound pressure level (L_{Aeq}) was measured using a sound level meter (RION NL-32).

The average sound pressure levels that male and female participants adjusted to represent soft and loud, and the standard deviations of the adjusted values, are shown in Figure 4. The female participants adjusted sounds to lower sound pressure levels for both soft and loud judgments than did the male participants. The mean upper-range sound pressure level that female participants perceived as soft was lower than that of male participants. Similarly, the lowest sound pressure level that females perceived as loud was lower than that of male participants. The findings of gender differences in loudness perception from the rating experiment were confirmed by the adjustment experiment. The criteria for males and females perceiving the sounds as "soft" and "loud" were actually different. Female participants assigned the verbal expression of "soft" and "loud" for lower sound pressure levels than male participants did [12].

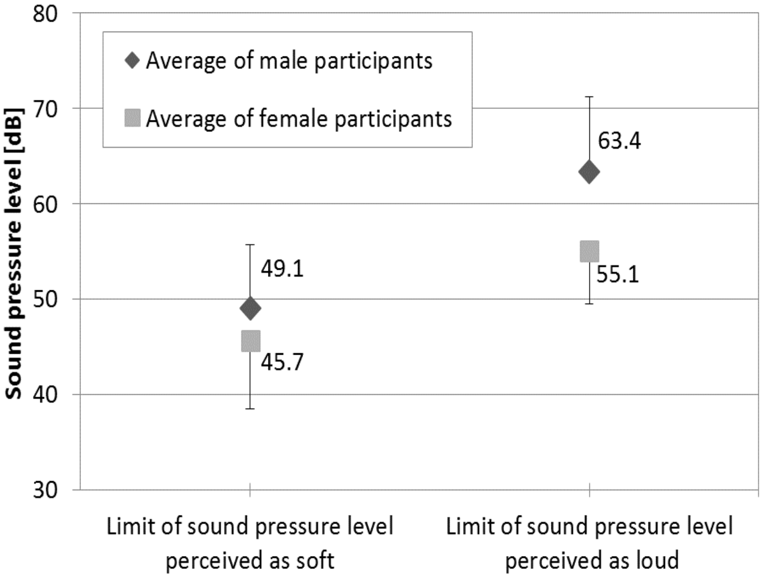

Figure 4 – Average limits of sound pressure levels for male and female participants' perceptions of soft and loud sounds. Error bars represent standard deviations.

4. RELATIONSHIP BETWEEN OLL AND OPTIMAL LOUDNESS

As chapter 3 makes clear, the gender difference in loudness ratings was observed regardless of frequency region, type of sound, range of sound pressure level or scale. The gender difference in loudness perception might be a factor affecting the gender difference in OLL. The relationship between these two phenomena was examined using regression analysis.

The regression analysis was applied to the results of the rating experiment using broadband noise (section 3.2). The rating score was the dependent variable, while the sound pressure level of broadband noise was the independent variable. The regression equation is expressed as $y = ax + b$ (a and b are constants). When the value of sound pressure level is x, the value of the predictive loudness evaluation is estimated as y. The regression equation for the male and female participants were obtained using Eqs. (1) and (2). The correlations of these equations were statistically significant ($p < 0.01$). The subscripts m and f indicate male and female participants.

$$y_m = 0.134x_m - 4.21 \quad \left(R^2 = 0.503\right) \tag{1}$$
$$y_f = 0.097x_f - 1.14 \quad \left(R^2 = 0.570\right) \tag{2}$$

To estimate the rating values of loudness for the OLL of music for male participants, the average OLL of the male participants for music (66.6 dB; section 2.1) was substituted into x_m of Eq. (1), resulting in y_m = 4.7. Thus, the male participants are expected to choose a rating of approximately 4.7 when the sound pressure level corresponding to their OLL for music (66.6 dB) is reproduced. To obtain the sound pressure level (x_f) that the female participants are expected to rate approximately 4.7, this value was substituted into y_f of Eq. (2), resulting in x_f = 60.2. The obtained x_f indicated that the sound pressure level that the female participants are expected to rate as 4.7 was 60.2 dB. The measured average OLL of the female participants was 60.6 dB.

The difference between the sound pressure levels that male and female participants perceived as 'optimal' was $x_m - x_f$ = 6.4. Thus, the difference in optimal loudness between the male and female participants was estimated as 6.4 dB. The measured difference in OLL between male and female participants was 66.6 – 60.0 = 6.6 dB. The estimated difference in sound pressure level that male and female participants perceived as 'optimal' (6.4 dB) from the rated loudness was almost equivalent to the measured difference in OLL between male and female participants (6.6 dB) [13].

5. PERCEIVED LOUDNESS ON THE RATIO SCALE FOR MALES AND FEMALES

The experiments described in chapter 3 found different criteria in males and females for judging sounds as "soft" or "loud." "Loudness" in the field of psychoacoustics is the psychological experience of sound intensity and is defined using a ratio scale [15]. However, the experiments in chapter 3 did not use a ratio scale. To examine gender differences in perceived loudness on the ratio scale, experiments using the methods of magnitude estimation and magnitude production were conducted. In this chapter, the gender difference in loudness change for the same change of sound pressure level is addressed.

5.1 Rating Experiment Using the Method of Magnitude Estimation

"Loudness" is defined by a ratio scale, with sones as the unit of measurement [15]. One sone is defined as the loudness of a 1 kHz pure tone at a sound pressure level of 40 dB. A sound with a loudness of 2 sones would, by definition, be perceived as twice as loud as a sound with a loudness of 1 sone. This experiment used the method of magnitude estimation to examine gender differences in perceived loudness on the ratio scale.

The stimuli and the method of presentation were the same as in section 3.5. The participants reported a positive value that corresponded to the loudness of presented sounds. The range of values that could be reported was unrestricted. The geometric means and geometric standard deviations of responses for the pink noise are shown in Figure 5. These geometric means values were calculated for males and for females, respectively. In contrast to the verbal ratings on the interval scale (chapter 3), no clear gender difference in mean values was observed here. The ratio of the minimum rating number and the maximum was larger for the females than for the male participants (males: minimum 6.07, maximum 32.8, and ratio 5.40; females: minimum 4.96, maximum 35.3, and ratio 7.12). Although assigned numbers for loudness of the stimuli were idiosyncratic to each participant, the ratio between the minimum and maximum numbers can be used for comparison. Similar tendencies were also shown in the 1/3-octave band noise cnditions. This suggests that the widths of perceived loudness rating for the same range of sounds pressure levels might be larger for the female than for the male participants. The difference in ratings on a ratio scale can be discussed using Stevens' power law [16].

S. S. Stevens proposed the power law to describe the relationship between psychological quantity and physical intensity of sensory stimuli [13]. According to the power law, psychological quantity (S) should be proportional to a power function of physical intensity (P) of stimuli, as shown in Eq. (3), where k and α are constants.

$$S = kP^{\alpha} \tag{3}$$

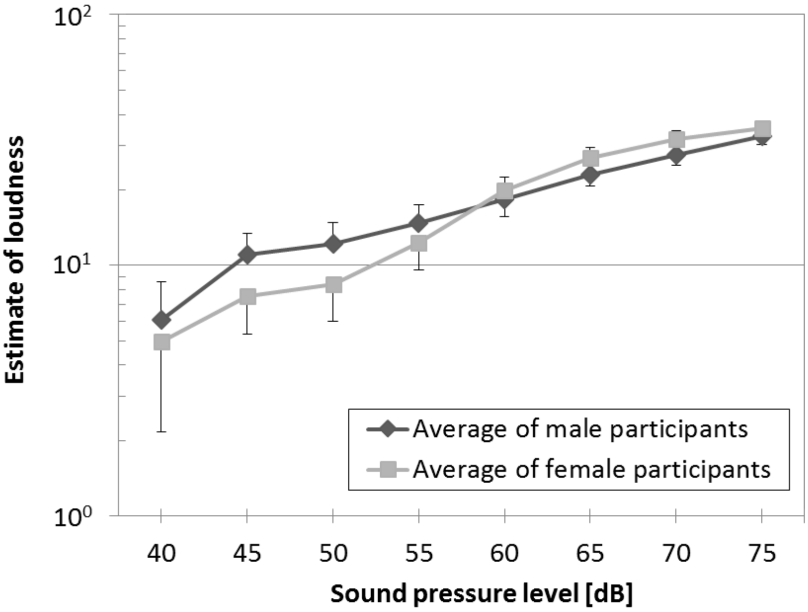

Figure 5 – Geometric means and geometric standard deviations of loudness values assigned by male and female participants for pink noise. Error bars represent standard deviations.

The power exponent α is different for different types of stimuli. The exponent is estimated at 0.6 between loudness and sound pressure [16]. As differences in perceived loudness ratings on a ratio scale for the same range of sound pressure level increase, so does the power exponent. To compare the power exponent α in Eq. (3) between male and female participants, regression analyses were applied to male and female participants' logarithmically converted loudness ratings for each sound pressure condition.

The average values of estimated power exponent α and standard deviations for each stimulus for the male and female participants are shown in Table 1. The Mann–Whitney U test was applied to the averaged power exponent α for male and female participants' data for each stimulus. Although the values of α were generally larger for female than for the male participants, the difference in averages was not statistically significant in any of the conditions; i.e., the gender difference in variation of perceived loudness for the same sound pressure level difference was not clearly evident in this analysis. For the same increase or decrease in intensity of sound, male and female participants made similar proportional changes in their loudness ratings on a ratio scale.

Table 1 – Male and female participants' power exponents α of Stevens' power law for each stimulus. Standard deviations are shown in parentheses.

Center frequency/ Type of noise	Males	Females
125 Hz	0.505 (0.118)	0.554 (0.307)
250 Hz	0.533 (0.160)	0.627 (0.421)
500 Hz	0.492 (0.205)	0.569 (0.264)
1 kHz	0.504 (0.166)	0.422 (0.306)
2 kHz	0.560 (0.177)	0.583 (0.311)
4 kHz	0.474 (0.156)	0.575 (0.328)
8 kHz	0.451 (0.101)	0.491 (0.240)
Pink noise	0.383 (0.065)	0.516 (0.264)

5.2 Experiment Using the Method of Magnitude Production

An experiment using the method of magnitude production was conducted to allow comparison with the results of magnitude estimation experiment. The same pink noise was used as both the reference and the adjusting sound. The sound pressure level of the reference sound was adjusted to 53.3 dB (L_{Aeq}), the average of the value that represented participants' judgments of "soft" and of "loud" sounds in the experiment described in section 3.6. The reference and adjusting sounds were presented from a loudspeaker positioned 2 m in front of the participants, as in the previous experiments. The duration of the reference sound was 5 s. After listening to the reference sound, participants heard an adjustable sound at the same sound pressure level as the reference sound. They were instructed to drag a mouse to adjust the loudness of adjustable sound until it was either half or twice as loud (depending on the experimental condition) as the reference sound. Participants made 10 total adjustments (five in the halving condition, and five in the doubling condition). The order of conditions was determined randomly on each trial. Participants were not restricted in the number of times they could listen to the sound stimuli or in the number of attempts they could make to adjust the adjustable stimulus. The L_{Aeq} of adjusted sound pressure level was measured using a sound level meter (RION-NL 32) at the end of each trial.

The average sound pressure levels that male and female participants chose to create sounds that they perceived as half or as twice as loud as the reference sound (53.3 dB) are shown in Figure 6. When a one-way ANOVA was conducted for each condition, the effect of gender was statistically significant in the halving condition ($F[1,98] = 10.914$, $p < 0.01$). As shown in Figure 6, male participants adjusted to lower sound pressure levels than did females in this condition. In the doubling condition, the gender difference was not statistically significant.

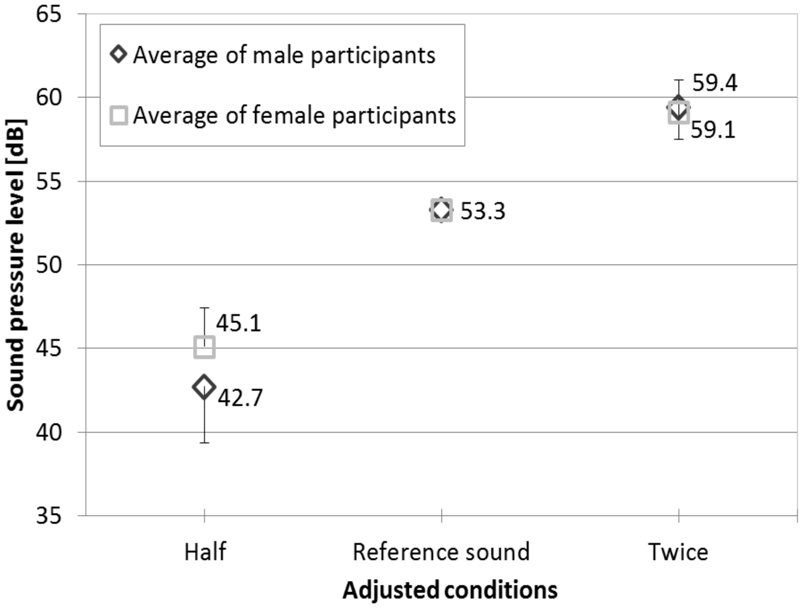

Figure 6 – Average sound pressure levels for males' and females' adjustments to halve or double the loudness of the reference sound (53.3 dB). Error bars represent standard deviations.

The obtained values of α for male and female participants in each adjustment condition are shown in Table 2. The values of α for female are greater than those for male participants in both conditions. Female participants might require less variation in sound pressure level to perceive the loudness of sound as half or twice as loud as the reference sound than male participants do.

Taken together, the experiments in this chapter, using magnitude estimation and magnitude production of loudness, did not show convincing evidence of a gender difference in loudness perception. However, the possibility of presence of gender difference in the relathionship between psychological quantity and physical intensity of sensory stimuli was shown.

Table 2 – Male and female participants' power exponents α for each adjustment condition.

	Half	Twice
Males	0.432	0.689
Females	0.589	0.782

6. CONCLUSIONS

A gender difference in OLLs of various sounds was observed, wherein male participants set higher OLLs than did female participants. The rating experiment on perceived loudness revealed that female participants rated sounds lounder than did their male counterparts, irrespective of the frequency region, type of sounds, range of sound pressure levels or scale used. The gender difference in optimal loudness was approximately equal to the gender difference in OLL. The gender difference in loudness perception of sound would be a factor affecting the gender difference in optimal listening level.

When a ratio scale was used for evaluation of perceived loudness, no clear gender difference emerged. Differences in loudness judgments between men and women may actually reflect differences in the use of verbal expression rather than differences in perception of intensity.

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