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Hearing: individual differences in perceiving†

Diane McGuinness
Department of Psychology, University College London, Gower Street, London, WC1E 6BT
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Abstract. Four different types of hearing were investigated using 25 men and 25 women as subjects: pure tone threshold, judgment of loudness, pitch discrimination, and annoyance of a repeating stimulus.

Differences were found at high frequency thresholds (above 6000 Hz), in loudness judgment, and in the annoyance test. The pitch discrimination test showed no effect of sex, but a large effect of years of musical training. None of the four hearing parameters investigated bore any statistical relationship to any other, demonstrating that these hearing types are distinct and will vary *within*, as well as between subjects. Personality assessment showed no relationship to any type of hearing, with the exception of extraversion and loudness judgment, suggesting that fairly pure sensitivity factors are being measured.

1 Introduction

Studies of individual differences tend to concentrate on personality correlates of behaviour, largely ignoring the question of differences in subjective perceiving as well as the basic difference of sex. As behaviour is dependent to a large extent upon the reaction to perceived events, knowledge of how perception differs between individuals may provide a greater understanding of how differences in behaviour arise. The study presented here has concentrated on simple auditory perception with the specific aim of delineating the degree of variation in subjective responding while strict equality of objective stimulation is maintained.

The experiment attempted to demonstrate further that response efficiency to auditory input will differ within individuals depending upon the type of auditory task. To illustrate this, it is not necessary to assume that 'good' or 'bad' hearing applies to all types of auditory perception. A person with a poorer than average auditory threshold could have superior ability in pitch discrimination. The auditory system may well function efficiently at one level, but less so at another. If this proves to be the case, we cannot speak of hearing in any qualitative sense, nor even as being a unitary phenomenon. Specific types of hearing must be established in order to define that which makes up the total perceptual experience for any one individual.

Four types of hearing were investigated: (i) pure tone threshold, (ii) judgment of intensity, (iii) pitch discrimination, and (iv) degree of annoyance to a repeating stimulus. More complex hearing processes involving rhythmic, temporal, harmonic, and verbal discrimination will be explored at a later stage. All subjects were given the IPAT anxiety, neuroticism, and extraversion tests (Cattell *et al.*, 1954; Scheier and Cattell, 1961; Cattell and Scheier, 1963) to determine whether personality type had any marked effect on hearing.

Because experiments on hearing seldom combine more than two types of measure, predictions of correlational relationships are not possible. The only observation which is adequately documented are the threshold norms for males and females, which show the females to have less hearing loss at frequencies above approximately 4000 Hz. (Corso, 1959; Eagles *et al.*, 1963; Hull *et al.*, 1971.) Sex differences in

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judgment of intensity have been investigated only in children (Elliott, 1971), whereas conflicting findings exist with regard to the relationship between intensity, noise evaluation, and personality (Smith, 1968; Pearson and Hart, 1969; Stephens, 1970). Studies on pitch acuity have tended to concentrate mainly on the performance in detail of a limited number of subjects (Henning, 1966; Attneave and Olson, 1971). Few studies have looked at the relationship between any of the four variables under consideration, with the exception of investigations comparing loudness estimation with threshold (Hood, 1968; Stephens, 1970, 1971; Stephens and Anderson, 1971).

The measurement of subjective phenomena is prone to the obvious difficulty of requiring subjective reports and interpreting these in an objective fashion. Therefore all measurement was restricted to either manual operations by the subject or to single word responses.

2 Method

Subjects

Fifty subjects (25 male, 25 female) participated in this experiment, all of whom were students at University College London. The age range was from 18 to 26 years, with a mean age of 20·6 years.

Apparatus

The experiment was carried out in a windowless acoustically tiled room. Parts 1 and 2 used a Peter's SPD 5 clinical audiometer, with TDH-39 earphones and MX-41/AR cushions. The audiometer was checked for calibration using an artificial ear, both prior to the experiment and immediately after the experiment was completed. Calibration was found to be satisfactory at the conclusion of the experiment. The calibration figures available for the SPD 5 audiometer allowed the frequencies of 10000 and 12000 Hz to be checked only for relative accuracy. The data recorded at these frequencies were reported for threshold, but no analysis was carried out above 8000 Hz. Part 3 was a pitch discrimination test which employed a Furzehill RC oscillator, GH32. The oscillator was wired into a key switch and into a 10 W amplifier which relayed the signal to an 8 Ω loudspeaker. This circuit successfully eliminated any load switch.

Procedure

The subject was seated with his back to the audiometer for the first part of the experiment, and was instructed to keep a button depressed as long as he could hear a tone, but to release it when the tone faded away completely. The button illuminated a light which could be seen by the experimenter. The subject was asked to place the earphones on his head with all his hair pulled back from his ears. He was asked to readjust the earphones once they were in position while an audible tone was sounded. This was done in order to ensure maximum volume.

The subject was told that he would be presented with a series of continuous tones of different frequencies and that each ear would be stimulated separately. The sequence adopted was left–right, right–left, left–right, etc. The subject heard frequencies of 125, 250, 500, 1000, 2000, 3000, 4000, 6000, 8000, 10000, and 12000 Hz, and, apart from the alternation procedure, these were presented using the recommended audiometric technique. All subjects had two descending and two ascending trials for each ear at each frequency. Each frequency change began at a completely audible level, and thresholds were measured to the nearest decibel.

Part 2 of the experiment consisted of a loudness level judgment. Here, the subject was seated facing the audiometer and was controlling the equipment. He was asked to adjust the attenuator to a decibel level which he felt was 'too loud'. It was stressed that what the experimenter required was a purely subjective estimate of the stimulus and that he was in no way interested in tolerance. A verbal rating scale was given as follows: inaudible, faintly audible, distinct, fairly loud, too loud, uncomfortably loud, pain. The subject was instructed that at the point where a 'fairly loud' tone became 'too loud', he should stop the attenuator and his response would be recorded. After this the experimenter reset the attenuator to some arbitrary level and the procedure was repeated two more times. Each subject had three trials at all the frequencies in the range 250–8000 Hz in random order, and he had his eyes closed throughout all trials. All tones were presented monaurally to the ear with the best overall threshold. If this could not be determined, the subject received left ear presentations.

In part 3 the subject was seated facing a loudspeaker with his back to the oscillator. The pitch discrimination test proceeded as follows: A standard was presented for 1 s, followed by 0·5 s silence, and then a comparison tone sounded. The subject was asked to respond 'same' or 'different' and was told he was not expected to tell whether the pitch went up or down. Volume was controlled at 60 db.

The standards were 500 and 1000 Hz. There were eight different comparison tones to each standard at differences of 1%, 2%, 4%, and 8% in both directions to the standard. These were included twice in each presentation using a random sequence. There was a total of 16 'different' and 8 'same' judgments to each standard, giving a possible total error score of 48. Error scores were recorded for both series, and 'same' error scores were halved. This was done to reduce the effects of the particular strategy of saying 'same' when uncertain, which given the ratios employed (four difficult 'different' judgments to 8 'same') was more advantageous than saying 'different'.

In part 4 each subject was asked to respond to the question: "If there was a clock ticking in your bedroom at night would you..." in one of four ways: (i) not notice it, (ii) find it soothing, (iii) find it irritating but ignore it, (iv) get up and put it away.

At the beginning of the experiment the subject filled in a questionnaire giving details of age, sex, preferred hand, years of musical training, name of instrument(s) played, hearing difficulties or abnormalities; and for women also: whether or not they were taking the contraceptive pill, and the day of their menstrual cycle.

At the end of the experiment all subjects completed the IPAT anxiety, neuroticism, and extraversion scales (Cattell *et al.*, 1954; Scheier and Cattell, 1961; Cattell and Scheier, 1963).

3 Results

No subject exhibited a noticeable hearing defect in more than one ear. All data reported are on best ear performance only.

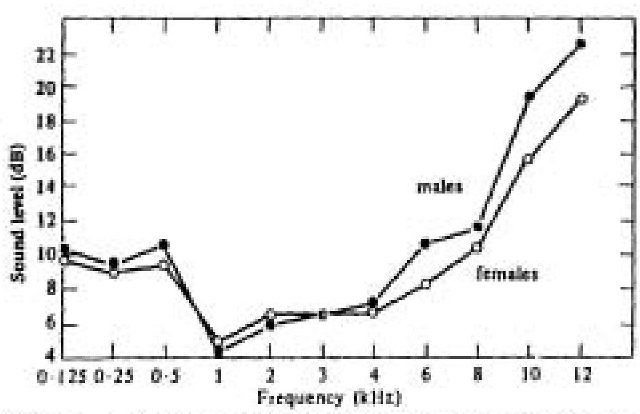

Figure 1. Thresholds for males and females at the test frequencies.

Part 1. Threshold

Thresholds for males and females at all test frequencies are presented in figure 1. They are fairly typical for this age group, and illustrate that in this sample men and women are extremely evenly matched. The men have considerably less hearing loss than normal in the range 3000–6000 Hz.

The mean threshold levels for each frequency are in decibels (referred to 2×10^{-5} N m^{-2}, or SPL). No statistical analysis was carried out on any portion of these curves.

Part 2. Loudness

The results for the loudness judgment test are presented in figure 2, where it can be seen that the difference level between men and women is practically constant across the entire frequency range. Loudness estimations were remarkably consistent within individuals, seldom varying more than 5 db for any frequency.

Distributions were normal, with only a marginal leptokursis for women who had a tendency for scores to fall further below the mean than above it. The standard deviation for the men was 13·45, and for the women 15·72. An analysis of variance showed the sex difference to be significant at $p < 0{\cdot}001$, with no significant effect of frequency and no significant interaction. (F, 7 and 268, = 28, <1, <1.) The audiometer had an automatic cut-out device for the frequencies 125, 10000, and 12000 Hz; hence the analysis was performed only on the scores in the range 250–8000. The mean loudness level over all frequencies was 83·3 db for men and 75·5 db for women.

Part 3. Pitch

Table 1 shows the mean error scores for each sex split into three categories of high, medium, and low musical background. 'High' means that the subject had had five or more years of musical training on any instrument or combinations of instruments, or that the instrument was self-taught and played continuously for a period of six years

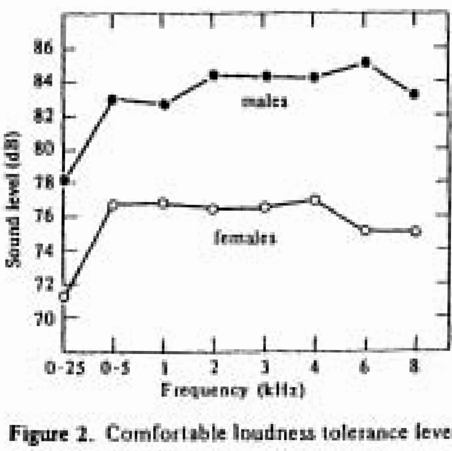

Figure 2. Comfortable loudness tolerance levels for males and females for the criterion: 'too loud'.

Table 1. Pitch acuity mean error scores.

	Musical background			Overall
	high	medium	low	
Females	5·22	7·56	10·08	7·60
Males	5·56	8·83	10·30	8·26

or more; 'medium' implies from two to four years training, or three to five years if self-taught; and 'low' one year or less training, or less than three years if self-taught. No subject produced an errorless performance. The best error score was two incorrect from a female who played three instruments including violin. Men and women did not differ significantly in their test scores (t test $p < 0{\cdot}20$). The data for both sexes were combined and analyzed using a Kruskal–Wallis test to determine the effect of musical training. This result was significant at $p < 0{\cdot}005$, and showed that musical training in terms of number of years spent on any instrument was significantly related to better pitch discrimination.

Part 4. Clock test
An analysis was carried out on the clock questionnaire replies using a Kendall's S for dichotomized trend. This produced a z score of 2·01 which was significant at $p < 0{\cdot}03$, showing that women were increasingly more annoyed by a ticking clock than were men. The number of positive replies in each category is given in table 2.

Personality tests
While English students are equivalent to American students in neuroticism and extraversion distribution, they are considerably more anxious (this finding was also noted by the author on a sample of 80 adult students). As a correction is built into the scoring procedure for sex differences, no statistical analysis was performed on these scores. Raw scores show women to be more anxious than men, but no difference in N or I–E scores is found (Cattell *et al.*, 1954; Scheier and Cattell, 1961; Cattell and Scheier, 1963).

Correlational data
Threshold and loudness. The correlations for threshold and loudness tolerance at all frequencies are given in table 3, where it is shown that no fixed pattern is found between threshold and loudness judgment. This means that having a high or a low threshold bears no relationship to the subjective sensation of loudness. The tendency to negative correlations found in men's scores corresponds to the findings by Hood (1968) who used only men as subjects. There is no similar type of study with which to compare the positive correlations found with women. The significant correlations for men at the frequency range 2000–4000 Hz may have some relationship to findings by Hood who investigated this only at 1000 Hz.

Threshold and pitch. The correlations between pitch error total scores and threshold at 1000 Hz were for the men −0·33, and for the women 0·09. Neither of these correlations are significant, demonstrating that having acute hearing at threshold

Table 2. Number of subjects in clock test categories of affect.

	Nil	Positive	Negative	Avoidance
Female	6	3	7	9
Males	16	0	4	5

Table 3. Correlations between threshold and loudness judgment.

	Frequency (Hz)							
	250	500	1000	2000	3000	4000	6000	8000
Females	0·11	0·13	0·23	0·14	0·14	0·21	0·19	0·36[a]
Males	−0·12	−0·09	−0·10	−0·45[a]	−0·49[a]	−0·43[a]	0·11	0·12

[a] $p < 0{\cdot}05$.

does not indicate that a person will be accurate in judging just noticeable differences in frequency.

Threshold and clock scores. Because of the limited number of clock categories, correlations could not be computed, and the data were analysed using a Kruskal-Wallis test. Clock scores were compared to the threshold scores for the frequency of 250 Hz, which is the nearest frequency measured to that of a ticking clock. It was found that women with *higher* threshold were significantly more adversely affected by a ticking clock ($p < 0 \cdot 02$). This relationship was not found for men ($p < 0 \cdot 20$). When the same test was carried out for a high frequency threshold (8000 Hz) no significant relationship was found for either sex ($p < 0 \cdot 20$).

Loudness and pitch. Pitch error scores were correlated with each subject's mean loudness tolerance for 500 and 1000 Hz combined (these levels were usually identical). identical). The results were for the men 0·15, and for the women 0·06. Neither of these results is significant.

Loudness and clock. Men's and women's scores were analyzed separately using a Kruskal-Wallis test. No significant relationship was found between loudness tolerance level and clock annoyance for either the overall mean score for each subject in the loudness test, or for the individual scores at 250 Hz ($p < 0 \cdot 20$).

Pitch and clock. Scores were analyzed as above with pitch errors ranged in the four clock categories. Men's and women's scores were analyzed separately using a Kruskal-Wallis test. No significant results were found ($p < 0 \cdot 20$) showing that musical ability has no relationship to annoyance of a repetitive stimulus.

Personality and hearing

No personality factor tested showed any relationship to threshold. When subjects were grouped into categories of high, medium, and low for each personality type and their threshold scores for 1000 Hz compared, there was a non-significant result (Kruskal-Wallis $p < 0 \cdot 20$).

A Kruskal-Wallis test also showed that there was no relationship of any personality factor to loudness estimation ($p < 0 \cdot 20$). A test of trend was employed (Jonckheere) to see if there was any tendency for increasing levels of loudness judgment to relate in any way to personality scores. Anxiety and neuroticism showed no significant trend ($p < 0 \cdot 20$) for either sex, but extraversion was found to relate to higher loudness estimation and introversion to lower estimation for women ($p < 0 \cdot 03$); this relationship was not found for men ($p < 0 \cdot 20$).

It might be expected that tolerance for a ticking clock would have some relationship to personality, but this is not the case. A Kruskal-Wallis test on these personality categories shows no significant relationship between personality and tolerance of a ticking clock for either sex ($p < 0 \cdot 20$).

Miscellaneous

Laterality. There was an equal division between right and left ears in efficiency at threshold for women, with men being more right-eared. When handedness was assessed in relation to best ear performance, no significant relationship was found (sign test $p < 0 \cdot 20$). Subjects with known ear damage or abnormal performance on the threshold test were eliminated for this analysis.

Menstrual cycle. Fifty per cent of all females tested were taking the contraceptive pill. Analysis was thus restricted to those subjects on a normal menstrual cycle. When women were grouped into categories of the four weekly cycle periods no relationship was found between any phase of the cycle and threshold ($p < 0 \cdot 20$).

This does not mean that a relationship would not be seen *within* subjects over the menstrual cycle, but this experiment did not include that type of measurement.

[It was also interesting to observe that those subjects taking the pill were significantly *less* neurotic than those not taking the pill ($p < 0{\cdot}02$). No other personality factor showed a significant relationship.]

4 Discussion

Two major findings have emerged from this study. The first is that sex differences contribute a much greater proportion of psychological variance in hearing than individual differences of personality, which might suggest that certain sex differences reported in the literature in tasks which involve listening could arise from the fact that the females hear the stimulus better (as louder) than the males. For example, subjective loudness doubling is ~10 db which indicates that at about 85–90 db females may hear the sound as *twice* as loud as men, although the definitive experiment remains to be done. The second finding demonstrates that there is no relationship between any of the types of hearing investigated, with the single exception of the finding that annoyance to a ticking clock relates to higher thresholds in women for the frequency 250 Hz. It is thus fairly conclusively demonstrated that there are three and possibly four hearing parameters which are markedly distinct.

The positive or significant results show substantial sex differences in high frequency threshold, favouring females. This finding is already well documented and need not be commented on further (Corso, 1959; Eagles *et al.*, 1963; Hull *et al.*, 1971).

The most striking sex difference was found in loudness judgment. It is curious that apart from Elliott's study on children (1971), in which he found almost identical loudness judgment differences to this study, the literature is almost devoid of any studies of this type. This difference is not unknown. Similar results have been obtained in loudness scaling experiments where subjects are asked to rate volume levels on a logarithmic scale. Here it is consistently shown that women have steeper slopes than men, but these findings have not been reported (Robinson, unpublished data). A recent experiment, where the subject was asked to adjust the intensity of an audiometer to match the intensity of a burst of sonic noise, showed that women consistently and significantly set higher intensity levels than the men (Rood, personal communication).

The absence of sex differences in pitch discrimination and the large effect of musical background suggest an important environmental effect on this particular type of ability. However, it is not easy to determine whether musical people take up an instrument because they have a discriminating ear, or whether the playing of the instrument *makes them* more discriminating. A finding that a few subjects with no musical background had excellent scores on this test supports the former argument. However, people who played string instruments, including guitar (where the tuning is done using harmonics) consistently scored higher than all other subjects, musical and non-musical, which supports the second argument. This indicates that some interaction between sensitivity and training is taking place to improve auditory discrimination.

The finding that women tolerate a repeating stimulus less well than men is difficult to explain in the light of the results of this experiment. The lack of any significant relationship to loudness estimation shows that the dislike of a ticking clock is not due to it being perceived as being louder, but is apparently due to the impact of the repetition rate. The significant result connecting this to threshold at the frequency of 250 Hz may be spurious as it does not explain the finding, particularly since the volume of a ticking clock is considerably above threshold and therefore should be much more related to loudness perception than to threshold levels. It could be possible that people who are annoyed by a repeating stimulus do not habituate readily in the Sokolov type of habituation (Sokolov, 1963), but habituation rate is known to relate to anxiety or neuroticism (Lader and Wing, 1966; Coles *et al.*, 1971) and this relationship was not found with these subjects. In an experiment by the author (in press) women were found to habituate more slowly than men with the personality factor of anxiety controlled. This might suggest that intolerance of a repeating stimulus relates in some way to speed of habituation.

The lack of relationship between personality and hearing in this experiment suggests that what has been measured are relatively pure sensitivity factors. The technique of using a rating scale with 'too loud' as one of several criteria has eliminated the common difficulty of an interaction with the personality factor of anxiety which occurs when measuring 'uncomfortable' or 'unpleasant' loudness levels (Stephens, 1971).

The only significant relationship between personality and hearing showed that female extraverts tolerated higher levels of loudness than introverts. Eysenck (1967) has suggested that a 'strong' nervous system with rapidly generated central inhibition relates to the personality type of extraversion, whereas a 'weak' nervous system with more slowly generated inhibition is characteristic of the introvert. The theory is too general to account for many types of reactions to stimuli (Coles *et al.*, 1971), but the suggestion could well apply at a more specific level, for example in an initial response to any stimulus where intensity is a significant parameter. In experiments on loudness, findings have been reasonably consistent in demonstrating that extraverts tolerate higher levels of intensity, but results appear to be more stable for women than for men (Elliott, 1971; Stephens, 1971; Stephens and Anderson, 1971). Therefore, if the sexes are combined in any attempt to relate personality to perception, which is most often the case, the chances of finding any lawful relationship may be considerably reduced.

The explanation of the sex differences in terms of mechanisms is problematic. Ward (1966) has proposed a theory which suggests that the sex differences which he has found in his studies on threshold shift after loud noise can be explained by a greater efficiency of middle ear muscles in women. In his experiment women were significantly less affected at low frequencies than men but more affected at high frequencies (above 3000 Hz). There has been evidence from experiments on cats that the middle ear muscle operates differentially over these two groups of frequencies. But this type of finding cannot account for the consistent differences found across all frequencies.

The general view concerning how the nervous system codes increments in intensity is that this occurs by a three-fold process of an increasing rate of discharge, summation (due to spreading excitation), and by a decreasing response latency (Simmons, 1970). However, Simmons also points out that much of the data do not fit these three explanations. One problem for the explanation of sex differences is that frequency discrimination increases as intensity increases, and many cells at all levels of the system respond to both inputs, showing a maximal sensitivity for varying frequencies at different levels of intensity. As no sex differences are found in discrimination, this double coding system cannot provide an easy explanation of the differences in the subjective experience of intensity.

An analysis of the neural mechanisms responsible for sex differences is almost impossible, giving the present state of knowledge about how coding occurs in the auditory pathways; therefore a more molar explanation in terms of general mechanisms of inhibition may be the most satisfactory. Pribram (1971) suggests that any stimulus input produces a two-fold inhibitory process involving both lateral inhibition and self (or recurrent) inhibition. If the efficiency of lateral inhibition is proportional to the enhancement of intensity, this could suggest that hearing signals as louder may be due to a finer tuning in this mechanism. Likewise, self-inhibition which affects the speed of return to base or steady-state firing levels, and is involved in habituation processes, may explain part of the result which showed that females have extra attentiveness to auditory repetitions. That both a heightened perception of loudness, as well as greater attention to auditory stimuli through delayed habituation, could be useful to the sex who tends the young, and who must be particularly sensitive to their vocalizations, puts the matter into some biological perspective.

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