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ASSESSMENT OF COMFORT AND DISCOMFORT LEVELS FOR PURE TONE, A METHODOLOGICAL STUDY

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ABSTRACT

Twelve subjects with normal hearing and six subjects with sensory-neural hearing loss were given two tasks: 1) to adjust the perceived loudness of a sinusoidal tone so as to correspond to each of five "loudness labels" and 2) to rate the perceived loudness of the same tone, presented at different sound pressure levels (SPL), on a scale with six "loudness categories". There was in general a great inter-individual variation in the curves relating the dB SPL to the different "loudness labels" (categories). The intra-individual reliability was high. The SPL values obtained at the rating (estimation) task were in general higher than those from the adjustment task. The relative reliability of the two methods is discussed, and the importance of the instructions is emphasized. The concepts of "Most Comfortable Level" and "Loudness Discomfort Level" are discussed in terms of perceptual regions rather than as single values.

INTRODUCTION

There is in audiology a great need of reliable methods for assessing an individual's "most comfortable level" (MCL) and "loudness discomfort level" (LDL) for various kinds of auditory stimuli. Knowledge of these levels may be an important complement to the data from the conventional audiometric testing for the purpose of diagnosing the hearing loss and deciding upon appropriate hearing aids, training procedures, etc., for the individual in question.

Some recent papers on these and related questions are those by Hood & Poole (1966), Hood (1968), Schmitz (1968), Kopra & Blosser (1968), Farrar (1968), Backman (1971), Ventry & Woods (1971), and Fausti (1972). These studies differ considerably among themselves as to problems and methods. Half of them is devoted to questions about the MCL, the other half to problems about the LDL. However, a joint treatment of both MCL and LDL does not appear in any of them. The stimuli used are sinusoidal tones of different frequencies and/or a speech section (recorded connected discourse) and/or noise bands. The MCL studies are in general performed with normal hearing subjects, while conversely the LDL studies are made with persons suffering from hearing loss; Farrar (1968), however, used both these types of subjects. The specific method for assessing the MCL or the LDL is usually some kind of adjustment method and/or estimation method. The instructions given to the subjects are explicitly given in some reports (for instance, Backman (1971), and Ventry & Woods (1971), while not in certain others, and Ventry & Woods emphasize the obvious impact instructions might have on determinations of MCL.

It seems clear from the results of these studies that the obtained values for the MCL or the LDL are dependent on many factors such as the type of stimuli, the judgement method, the instruction, the statistical treatment of the data, and (not the least) the selected subjects. As a rule a wide inter-individual variation in the results is found, the reasons of which may be speculatively ascribed to individual differences in various aspects as the physiological hearing mechanisms, the familiarity with high sound levels (for instance, working in a noisy environment or using a high-powered hearing aid over a considerable time), the way of interpreting terms as "comfortable loudness" or "discomfort" appearing in the instructions, motivational factors, and so on. The intra-individual variation, however, is often much lower, that is, an individual may be rather stable within himself as regards judgements of MCL or LDL.

In the present work an attempt is made to study both MCL and LDL on the same subjects. Rather than establishing one value for each of the MCL and LDL it seems preferable to conceive of a perceptual "comfort region", which may be bounded by a lower and an upper limit (Backman, 1971), and a "discomfort region" within which there are several possible "degrees" of discomfort (from, say, "slightly discomfortable" to "unbearable"). One may accordingly present to the subjects a number of "loudness labels" or "loudness categories", denoting such limits/degrees of the comfort and discomfort regions, and see whether these are used in a consistent way when the subjects make their judgements. This proposal is tested by means of an adjustment method and an estimation method to be compared between themselves as to reliability, validity, and results in general.

The experiment is designed as a methodological study in order to get a basis for continued work. Since there is no generally accepted method for assessment of MCL and LDL the interest is presently more concentrated on the response side than on the stimulus side. The stimulus used here is as yet solely a sinusoidal tone of 1700 Hz (hearing aids often show a resonance peak in this frequency region).

METHOD

Summary of method

Eighteen subjects, twelve of them with normal hearing and six with sensory-neural hearing loss, were given two different tasks. One of them consisted in adjusting the perceived loudness of a sinusoidal tone (1700 Hz) so as to correspond subjectively to certain verbally prescribed loudnesses (like "Comfortable loudness, on the limit of being too loud" or "Discomfortably loud, on the limit of being painful"). The other task consisted in listening to the 1700 Hz tone, presented at different sound pressure levels (roughly between 55 and 120 dB), and rating the perceived loudness of each such case on a verbal rating scale with six categories (for example, "Comfortably loud" or "Discomfortably loud", etc.). Each of the tasks was distributed over a number of experimental sessions.

Stimulus and test equipment

The test is controlled by a Mini Computer Honeywell 316 that belongs to the department, Fig. 1. A card reader, a dial, and lamps are connected to the computer for the experimenter's communication with the computer. The test subject has access to a keyboard for his own control of the test.

A 1700 Hz sine wave feeds a gate, which is controlled by the computer. When trigged, it gives a 700 msec long pulse with a rise time and a decay time of 40 msec. The sine wave pulse passes a variable attenuator, which is controlled in steps of 1 dB by the computer. After amplification, the signal is presented to the test subject binaurally in TDH 39 headphones with MX 41 A/R cushions. The resulting sound pressure level in the headphones can be varied from 40 to 130 dB.

The keyboard has three keys, marked "Tone", "+" and "-". The test subject must not press more than one key at a time. When the "Tone"-key is pressed, one sine wave pulse is fed to the headphones. When the "+" or "-" key is pressed, the level increases or decreases, respectively, in 1 dB steps with a speed of 3 dB per sec (inaudible to the subject).

The computer is programmed for control of the test, for collecting data and for calculating the results.

Subjects

There were in all eighteen subjects. Twelve of these (11 males and 1 female, 20-30 years old) had normal hearing (less than 20 dB hearing loss 250-8000 Hz /ISO R389/). Six subjects (2 males and 4 females, 30-53 years old) had sensory-neural hearing losses as given in Fig. 2.

Experimental procedure

Each subject participated in two different tasks, which will be called the adjustment task and the estimation task, respectively.

Adjustment task

In the adjustment task the subject adjusted the perceived loudness of the sinusoidal tone so as to correspond subjectively to certain prescribed loudnesses. Five such prescribed loudnesses, "loudness labels", were used (given in Swedish but here also translated into English):

1. Comfortable loudness, on the limit of being too soft
   (Sw. Lagom styrka, på gränsen till för svagt)
2. Comfortable loudness, on the limit of being too loud
   (Sw. Lagom styrka, på gränsen till för starkt)
3. Too loud, on the limit of being discomfortable
   (Sw. Alltför starkt, på gränsen till obehagligt)
4. Discomfortably loud, on the limit of being painful
   (Sw. Obehagligt starkt, på gränsen till plågsamt)
5. Painfully loud, on the limit of being unbearable
   (Sw. Plågsamt starkt, på gränsen till outhärdligt).

Each of these five "loudness labels" was written in large lettering on a piece of white cardboard, a separate piece for each label. The details of the procedure are seen from the instruction:

"In this experiment you will listen to short tones like these (demonstration of some cases with varying sound pressure levels). As you noticed the tones were different in loudness. During the experiment you can determine yourself when you want to hear the tone by pressing the "Tone" key (demonstration). To make the tone sound louder you press the key designated with a plus (+) sign. To make the tone sound softer you press the key designated with a minus (-) sign. The longer time you press the respective key, the greater the increase or decrease of the loudness will be.

We will now ask you to adjust the loudness of the tone so that you perceive it in such a way that is written on a sign-board which is shown for every new case. You thus carefully read what is written on the paper and reflect for a while which loudness of the tone it means. When you tell that you are ready the tone will be presented automatically. Then you use the "+" or "-" keys to get the tone to sound as written on the paper. After every change you have made press the "Tone" key again and so on until you are satisfied. Tell when you are ready and then wait for the next paper.

It is very important that you carefully read what is written on the different papers and really reflect upon which perceived loudness it means. The respective paper remains there all the time when you are making the adjustments and we should like you to look at it now and then to keep the words in your memory."

Each subject went through the following experimental sessions:

a) A first preliminary session to determine his audiogram and also his approximate "discomfort level" (only roughly by presenting short sine wave pulses (1000, and 2000 Hz) at an increasing sound pressure level and asking the subject to indicate when the loudness was definitely "discomfortable"; further an elicitation of the eye-blink reflex was taken as an index of "discomfort"). Thereafter the subject made a number of practice trials for the different "loudness labels" according to the instruction above. For the first four subjects the resulting values were used for the purpose of determining a range of appropriate "starting values" (that is, the sound pressure level of the tone when it is presented to the subject the first time before he starts making his adjustments) to be used in the following sessions. For all other subjects the starting points were randomized within the range 55-90 dB for all loudness labels (see further below).

b) Eight short experimental sessions each comprising one complete adjustment for each of the five "loudness labels" (plus one practice trial at the beginning). The order of the loudness labels was randomized with the restriction, however, that the "highest" label (no. 5) should be taken last to avoid possible TTS effects. The possible TTS effects are also the reason for making many short experimental sessions instead of a few, longer sessions. The eight sessions were distributed over four to ten days, with at most two sessions per day separated by at least four hours. (For practical reasons, however, the members of the hearing loss group had to make three sessions a day with shorter intervals in between).

A difficult problem here is the risk of a possible damage to the subject's hearing when working with relatively high sound pressure levels. To minimize this risk the stimulus tone had a rather "soft" onset (40 msec), was rather short (700 msec), and could not be set higher than 130 dB SPL. For the normal hearing subjects audiograms were taken again after completion of the experiment, and the subjects were also asked if they had noticed any kind of effects on their hearing due to the stimulation in the experiments.

A related problem is, of course, a possible (and understandable) negative reaction on the subject's side to listen to and work with stimuli so loud that they should even be perceived as "unbearable". To counteract this special information about the purposes of the experiment was given separately at the beginning. All subjects were paid.

Estimation task

In the estimation task the normal hearing subjects listened to the sinusoidal tone, presented at twelve different sound pressure levels between 55 and 120 dB. For the subjects with hearing loss the levels were chosen individually with regard to the results of the adjustment task and the rough "discomfort levels" (the ranges varying from 55-105 dB to 70-130 dB). For each level the subjects rated the perceived loudness as belonging to one of the six following "loudness categories":

1. Too soft	(Sw. För svag)
2. Comfortably loud	(Sw. Lagom stark)
3. Too loud	(Sw. Alltför stark)
4. Discomfortably loud	(Sw. Obehagligt stark)
5. Painfully loud	(Sw. Plågsamt stark)
6. Unbearably loud	(Sw. Outhärdligt stark)

The instruction was as follows:

"In this experiment you will listen to tones like these.... (demonstrations). The tones will vary in loudness. You can determine yourself when the tones shall appear by pressing the "Tone" key - then the tone will come after one second.

We ask you to judge the loudness of the tone according to a certain scale, which is shown on the response sheet in front of you. You thus have six categories to choose between: Too soft, Comfortably loud, Too loud, Discomfortably loud, Painfully loud, and Unbearably loud. For every tone you hear you write a cross for that category which seems to be the best for describing the loudness of the tone. Only one cross is allowed even if you hesitate between two categories.

Now reflect for a while over the meaning of the categories. Then your judgements may begin. You press the "Tone" key and prepare yourself for the tone, listen carefully and write a cross for that category which seems to be the most suitable one. Then you push the "Tone" key to get the next tone and so on.

Try to listen in a relatively "spontaneous" way and do not wait too long in writing down your judgement."

Each subject participated in the following experimental sessions:

a) A preliminary session with a number of judgements according to the instruction above but treated as practice trials only. (For those subjects who started with the estimation task audiograms and "discomfort levels" were taken before the practice trials.)

b) Five experimental sessions, each comprising six judgements per each of the twelve sound pressure levels used. In all there were thus 30 judgements per each sound pressure level. The sessions were distributed over three to five days with at most two sessions per day. For time reasons the number of judgements per level had to be confined to 24 for the members of the hearing loss group. The order of the levels within each block of the twelve different levels was randomized independently for each subject.

Since it is possible that the task made first may have an influence on the task made next, the order of the adjustment and estimation task was balanced over subjects so that half of the subjects in the normal hearing group made the adjustment task first and the estimation task next, while the other half had the opposite order. All members of the hearing loss group made the adjustment task before the estimation task. Afterwards the subjects answered certain questions related to their tasks and aimed to reveal something about the subject's working principles and the like.

To investigate the reliability of the data, five of the normal hearing subjects were retested about a month later according to the same procedures. At the original experiment they were not aware that this re-testing should take place.

Data treatment

a) The data from the adjustment task simply consisted of a number of dB-values for each of the five prescribed "loudness labels".

The arithmetic mean and the standard deviation of these values were computed for each loudness label within each subject, Tables I-II and Figs. 3-4. The arithmetic means and standard deviations over all subjects in the normal hearing group appear in Table I (the standard deviation refers to the dispersion of the individual means at the respective loudness labels). The corresponding data for the hearing loss group are given in Table II.

b) The data from the estimation task consisted for each individual in a matrix of the type given in Table III, that is, giving the frequency (the number of times) with which a certain sound pressure level (columns) was judged as belonging to a certain loudness category (rows). To compute dB-values corresponding to those of the different loudness labels at the adjustment task a linear interpolation process was used. For example, to find the dB-value corresponding to loudness label 1 (Comfortable loudness, on the limit of being too soft) that dB-value was interpolated at which half of the subject's 30 judgements would occur in (or actually occurred in) the "Too soft" category and the other half in the "Comfortably loud" category (or possibly also in higher categories). As corresponding to loudness label 2 (Comfortable loudness, on the limit of being too loud) that dB-value was computed at which half of the 30 judgements would occur in the "Comfortably loud" category (or lower) and the other half in the "Too loud" category (or higher) and so on for the following loudness labels up to the last loudness label 5. These computed values appear in the same tables and figures as those referred to above for the adjustment task.

For some subjects the maximum sound pressure level at the estimation task was not loud enough to elicit the judgement of "Unbearably loud" or even "Painfully loud" in half of the judgements. In these cases the values corresponding to loudness label 5 (and 4) could not be computed as described above but are given as minimum values (for example >120 dB). In the figures this is indicated by an arrow upwards from the data point in question.

RESULTS

Normal hearing group

As seen in Fig. 3 (and Table I) the curves describing the dB SPL (adjusted or estimated) as a function of the five loudness labels are all monotonically rising (as they should), that is, the "higher" loudness label, the higher dB value. Although some subjects said they were uncertain about the difference between "Discomfortably loud" and "Painfully loud" (or between "Painfully loud" and "Unbearably loud") there is no sign of a "reversal" in the functions between these loudness labels. The differences between the means of the successive loudness labels (the differences between loudness labels 1 and 2, 2 and 3, 3 and 4, 4 and 5) were all statistically significant at a 5% level within each subject (the tests were performed according to Dunn's multiple comparison procedure for a randomized design within each subject (Kirk, 1968)).

As expected, however, there is a large inter-individual variation as regards the dB values for each loudness label. For loudness label 1 subject 2 lies around 60 dB, while subjects 8 and 9 lie around 95 dB, the other subjects at various values in between. For loudness label 2 the inter-individual range goes from 89 dB (subject 2) to 113 dB (subject 9), at loudness label 3 from 96 dB (subject 7) to more than 120 dB (subject 9), at loudness label 4 from 101 dB (subject 1) to 126 dB (subject 12), and at loudness label 5 from 107 dB (subject 1) to 130 dB (subject 9). (These values are given as yet without consideration to whether they come from the adjustment or the estimation procedure. At the two highest loudness labels there might have occurred values greater than 130 dB were they allowed.) In view of such great inter-individual variation the mean data for the group as a whole are of limited value. The slope of the functions also varies considerably between subjects. For subjects 1, 6, and 8 the slope is rather "moderate" while it is rather steep for subjects 2, 5, and 12. (It should be pointed out that the equidistant marking of the loudness labels along the X-axis is quite arbitrary and does not imply any kind of assumed psychological equidistance.)

The intra-individual variation is considerably smaller than the inter-individual variation at all loudness labels (see standard deviations for the adjustment task in Table I). The average intra-individual standard deviation (taken over all subjects) is 3-4 dB at each loudness label. Subjects 8 and 10 have the lowest intra-individual variation (standard deviations roughly 1-3 dB), while subject 2 has the highest (standard deviations roughly 4-6 dB).

One way of expressing the amount of intra-individual variation is to estimate how much of the variance in a subject's data is accounted for by the levels in the independent variable (that is, the different loudness labels), and how much is due to residual variance. This is estimated by the ω^2 index, applying the principle of a randomized design within each subject (Kirk, 1968, p. 127). For the twelve subjects in the normal hearing group the variance accounted for by the different loudness labels varied between 83% and 97% at the adjustment task, and the amount of residual variance is thus low. To get an indication of the intra-individual variation at the estimation task the data from the estimation procedure within each subject were divided into three parts (data from the first third of the experiment, the second third, and the last third) and dB-values corresponding to the different loudness labels at the adjustment task were computed within each such part. Estimating ω^2 on these data indicated that the variance accounted for by the different loudness labels was as high as 95% or more within each subject.

The curves resulting from the adjustment task and from the estimation task are in general rather similar in their slope within each subject (with some exception perhaps for subject 10 and with reservation for the fact that the curve could not be drawn out fully at the highest labels for the estimation task at certain subjects). In some cases (for example subject 5) the two curves are practically identical. The most typical situation, however, is that the curve obtained from the estimation task lies higher than that from the adjustment task. The amount of difference varies between the subjects and there are some exceptions from this rule at the very lowest (or next to lowest) loudness label (subjects 2, 3, 8, 10, and 12). There is some tendency that the difference is greater at the higher loudness labels than at the lower ones (subjects 1, 2, 7, 10).

To see whether the "starting point" at the adjustment task had any influence on the final adjusted value (for instance if a lower starting point would tend to produce a lower final value than a higher starting point, etc.) the product-moment correlation between starting points and produced values was computed at each of the loudness labels for each of the subjects 1-4. Most of the correlations were low, positively or negatively, and widely differing in specific details between the subjects. So there seemed to be no definite relation between the starting point and the produced value. For the following subjects, therefore, the starting points were randomized within 55-90 dB for all loudness labels. A later computation of the same correlations for these subjects led to the same conclusions as for subjects 1-4.

The subjects' answers to the questions after the experiment revealed that the task was in general not judged as difficult, nor painful. However, most of the subjects noticed some form of after-effects due to the high sound pressure levels (as "stupefaction", "a certain defect of hearing", "ringings", "a little dizzy", "my head was singing a little"). The effects were reported to disappear rapidly. The audiograms taken 10 minutes after the last session suggested practically no TTS effects.

The subjects were also asked to make one adjustment for each of the loudness labels and to describe simultaneously in their own words how they worked. From the answers it seems that the intended meaning of the loudness labels was generally understood by the subjects. It was rather common to refer to imagined phenomena outside the actual stimulus situation as, for instance, if the loudness of the tone corresponded to the loudness of "normal conversation" or not, if it would be possible to listen to a tone of the same loudness for a long time or not, if it was possible to hear the tone without any effort (at the lowest loudness label), and the like. For the highest loudness labels it was common to refer to actually experienced phenomena as "I feel some pain in the ears", "I am deafened", "a tingling sensation in my ears", "my ears are ringing", "a powerful pressure in my ears", etc.

Five subjects (no. 6, 7, 9, 10, and 11) were retested about a month later. The maximum sound pressure level at the estimation task was increased to 125 or 130 dB (depending on the subject's result in the original test) and the minimum sound pressure level increased to 65 or 70 dB. The results are given in Fig. 3 and Table IV. In comparison with the data from the original test the levels are in most cases higher, especially at the adjustment task (a mean increase over subjects and loudness labels with approximately 5 dB as against approximately 1 dB at the estimation task). The changes vary with the subjects, however, the most marked increases occurring for subjects 7, 10, and 11 at the adjustment task. This leads to a closer correspondence between the levels from the adjustment task and the estimation task now than in the original test. Still, however, the levels obtained at the estimation task are higher than those at the adjustment task (except for the lowest loudness label in subject 10).

These five subjects were asked if they were aware or could think of some reason why the levels at the estimation task were in general higher than at the adjustment task. A certain cautiousness at the production of the highest loudness labels was suggested by two subjects. Two other subjects pointed out that when making the adjustments at the highest loudness labels one generally produces tones at high loudness levels a large number of times within a short time, which gives rise to "irritation" and a certain tendency to get finished as soon as possible, possibly resulting in a lower sound pressure level than the most "true" level for the respective loudness label. At the estimation task, however, the different loudnesses occur in a more varying way so that the high sound pressure levels do not occur so concentrated in time.

Hearing loss group

The results are given in Table II and Fig. 4. In general the results show the same characteristics as for the normal hearing group. The curves in Fig. 4 are monotonically rising (except for one reversal in subject 15). The differences between the means of the successive loudness labels within each subject were all statistically significant at a 5% level for the data obtained from the estimation procedure. For the data from the adjustment procedure, however, this was true only for subjects 16 and 17, partially true for subjects 14, 15, and 18, and not at all true for subject 13.

There is a considerable inter-individual variation as regards the resulting sound pressure levels at the different loudness labels: at loudness label 1 from 68 dB to 96 dB (subjects 14 and 15, respectively), at loudness label 2 from 85 dB to 113 dB (subjects 14 and 16), at loudness label 3 from 92 dB to 122 dB (subjects 14 and 15), at loudness label 4 from 92 dB to 127 dB (subjects 14 and 17), and at loudness label 5 from 93 dB to more than 130 dB (subjects 14 and 17). These ranges are rather similar to those obtained for the normal hearing group (see above). The slopes of the curves also differ considerably between the subjects. The mean data for the group as a whole are thus of limited value.

As for the normal group the intra-individual variation is smaller than the inter-individual variation (see standard deviations for the adjustment task in Table II). The average intra-individual variation (taken over all six subjects) is roughly 4-6 dB, somewhat varying between the different loudness labels, and is thus greater than for the normal hearing group. Subject 16 has the lowest intra-individual variation (roughly 1.5 - 3.5 dB), while subjects 13-15 in most cases have an intra-individual variation of roughly 4-7 dB.

Estimating the ω^2 index in a way analogous to that for the normal hearing subjects led to the conclusion that the variance accounted for by the different loudness labels was definitely lower than for the normal hearing subjects at the adjustment task. For four of the six subjects the variance accounted for was roughly 50-65%, for the remaining two subjects, however, it was over 90%. At the estimation task, however, the variance accounted for by the different loudness labels is 95% or more for all six subjects, that is, as high as for the members of the normal hearing group.

The values obtained at the estimation task are in general higher, often considerably so, than those at the adjustment task. Exceptions occur at the lowest loudness label for three subjects (no. 13, 14, and 18). There might be a tendency that the difference in results between the two methods is greater at the higher loudness labels.

To see if there was any relation between the hearing threshold (for 1500 Hz) and the dB-values obtained for the different loudness labels the product-moment correlations between these variables were computed (and corresponding plots inspected). In the hearing loss group there was a high positive correlation meaning that the greater the hearing loss, the higher are in general the values obtained for the different loudness labels, and vice versa. This is especially evident when comparing the results for subject 14 with those for the other subjects. This subject has a much smaller hearing loss than the others (see audiograms in Fig. 2) and also gets lower dB-values at the different loudness labels (see Table II). (Interestingly enough the correlation between the hearing threshold and the loudness label values was higher when computed for the left ear than for the right. This might be related to the fact that all subjects but one had a greater hearing loss in the left ear than in the right.) Due to the small number of subjects in this group, however, these results should be taken with great caution and presently be regarded as suggestions only.

For the members of the normal hearing group, there seemed on the contrary to be no systematic relation between threshold values and loudness label values (the correlations were typically lower than ±0.25). It should be pointed out, however, that the range of threshold values over subjects was 10 dB only (0 to 10 dB hearing loss).

DISCUSSION

By and large the procedures used in this experiment seem to work in a satisfactory way, considering the exploratory nature of the investigation.

The short definitions of certain "loudness labels" and "loudness categories" for use in the adjustment and estimation task, respectively, resulted as expected in monotonic rising functions (Figs. 3-4). The large inter-individual variation is not surprising in view of similar results in earlier research. The standard deviations over subjects (Tables I and II) are of the same order or smaller than those reported elsewhere (Kopra & Blosser, 1968; Backman, 1971; Ventry & Woods, 1971). Group mean data are thus of limited value and reporting of individual data is a necessity, especially when dealing with hearing loss subjects. The intra-individual variation is in general much smaller than the inter-individual variation, and the amount of variance accounted for by the different loudness labels (estimated by the ω^2 index) is high within each subject, especially at the estimation task.

For most subjects the estimation method resulted in higher dB-values at the different loudness labels than those from the adjustment method, a few exceptions from this occurring at the lowest loudness label(s). Some possible reasons for this situation were suggested by the subjects themselves (see under Results), indicating a certain cautiousness and "unwillingness" (quite understandably) to produce oneself the high loudnesses required for loudness labels 4-5. Such restrictions, however, are not possible at the estimation task (in which the stimulus presentation is beyond the subject's control), and evidently most subjects then tolerated higher sound pressure levels for the same loudness labels than at the adjustment task. The criteria used for the judgements thus seem to be different for the two methods. Which of them should be considered to give the most "true" result may depend on the specific purposes with each separate investigation, which of them seems most similar to a "realistic" listening situation, etc. It may be noted that at the retest of five subjects the main change occurred for the adjustment data which were increased to higher sound pressure levels (compared to the data from the original test) and thus approached the data obtained from the estimation procedure.

There are certain indices that the reliability of estimation data may be higher than for adjustment data. The amount of change at the retest of five subjects was smaller for the estimation task than for the adjustment task. The ω^2 index, giving the amount of variance accounted for by the different loudness labels, was in general higher for the estimation data than for the adjustment data. This was especially obvious for four of the subjects in the hearing loss group. (However, all subjects in this group made the estimation task after the adjustment task which may be a contributing factor to the difference. It should also be noticed that at the estimation task the subjects saw all the loudness categories to choose between simultaneously on the response sheet, while at the adjustment task they looked at one of the loudness labels at a time. This difference might have importance for the relative reliability of the methods.)

In the instruction to the subjects they were asked to judge the loudness of the tone presented in the earphones. Apparently, however, many subjects tried to find criteria for their judgements outside the stimulus situation, for example, by imagining if the loudness of the tone corresponded to normal conversation level or not (see under Results). This may be seen as examples of "self-instructions" and since different subjects probably give themselves different "self-instructions" this may contribute, among many other factors, to the inter-individual variation in the results. This emphasizes the need of still more precise instructions, and it may be preferable to manipulate instruction variables and look for their effects on the data (Ventry & Woods, 1971). It may be preferable, too, to further elaborate on the intended meaning of the loudness labels/categories by supplying more concrete information and examples to the subjects. All these questions are further dependent on the type of stimuli used and on the specific purpose with each investigation.

Comparison between the two subject groups should be made with great caution due to the small groups and due to the great inter-individual variation. Some subjects in the hearing loss group had less reliable data at the adjustment task. A positive correlation between hearing threshold and values obtained for the different loudness labels was found for the hearing loss group, however not for the normal hearing group. Some earlier data on this point are found in Hood & Poole (1966), Hood (1968), Farrar (1968), and Backman (1971).

Some suggestions for further research were given above. Above all, however, the future work is planned to include other types of stimuli and be more concentrated on subjects with hearing loss. This will in its turn necessitate many modifications in instructions and procedures, considering the limited vocabulary of many hard-of-hearing persons, the difficulty of getting homogeneous groups, etc. However, the present work has demonstrated the possibility of working with some different limits or degrees of the experienced "loudness comfort" and "loudness discomfort", respectively, and this notion will be a convenient reference frame to be refined and adapted to various purposes in experiments to follow.

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Table I. Individual values for the adjustment task (arithmetic means; standard deviations in parenthesis) and for the estimation task (means) at each of five "loudness labels" for the subjects in the normal hearing group. Mean values over subjects ($\bar{X}$) and standard deviations (s) over subjects (s = standard deviations of the individual means at the respective loudness label) appear in the bottom margin.

Subject No.	Loudness labels									
	1		2		3		4		5	
	Adj.	Est.	Adj.	Est.	Adj.	Est.	Adj.	Est.	Adj.	Est.
1	78 (3.7)	89	94 (3.2)	102	99 (4.3)	109	101 (3.9)	114	107 (5.5)	120
2	61 (5.6)	57	89 (5.9)	96	101 (4.3)	110	105 (4.1)	117	112 (5.2)	>120
3	95 (4.2)	90	104 (4.6)	104	117 (4.4)	117	122 (5.3)	>120	129 (2.1)	>120
4	92 (3.5)	92	105 (2.1)	104	111 (3.0)	113	117 (3.3)	>120	128 (4.8)	>120
5	71 (6.1)	73	94 (5.0)	95	104 (2.6)	105	109 (2.9)	111	117 (1.6)	119
6	83 (4.5)	88	97 (1.9)	102	101 (2.7)	105	108 (5.3)	113	114 (3.5)	116
7	69 (3.8)	73	90 (1.1)	95	96 (1.4)	104	106 (3.3)	114	113 (4.5)	>120
8	98 (1.1)	92	101 (2.6)	104	111 (3.0)	113	114 (2.9)	116	127 (1.7)	>120
9	94 (4.0)	95	109 (3.3)	113	116 (4.9)	>120	123 (4.8)	>120	130 (1.1)	>120
10	89 (1.2)	84	96 (1.4)	105	102 (3.1)	114	105 (3.3)	120	118 (1.7)	>120
11	82 (3.9)	94	94 (2.6)	104	100 (4.5)	114	112 (4.2)	>120	126 (2.5)	>120
12	75 (4.3)	82	110 (5.3)	107	118 (5.2)	120	126 (3.5)	>120	129 (1.2)	>120
$\bar{X}$	82	84	99	103	106	>112	112	>117	121	>120
s	11.2	10.8	6.8	5.2	7.2	5.3	7.8		7.8	

Table II. Individual values for the adjustment task (arithmetic means; standard deviations in parenthesis) and for the estimation task (means) at each of five "loudness labels" for the subjects in the hearing loss group. Mean values over subjects ($\bar{X}$) and standard deviations (s) over subjects (s = standard deviations of the individual means at the respective loudness label) appear in the bottom margin.

Subject	Loudness labels									
	1		2		3		4		5	
No.	Adj.	Est.	Adj.	Est.	Adj.	Est.	Adj.	Est.	Adj.	Est.
13	85 (10.6)	80	91 (6.2)	98	98 (2.0)	108	98 (8.9)	112	101 (3.9)	>115
14	74 (5.2)	68	85 (4.3)	88	92 (6.7)	97	92 (5.0)	>105	93 (3.7)	>105
15	94 (4.3)	96	96 (7.0)	113	111 (4.9)	122	109 (6.0)	126	113 (7.5)	>130
16	97 (1.4)	96	109 (2.3)	113	116 (1.9)	119	121 (3.7)	123	127 (3.3)	128
17	92 (3.6)	93	99 (3.4)	109	112 (4.5)	120	119 (3.9)	127	125 (2.4)	>130
18	94 (8.9)	85	97 (5.4)	104	101 (4.7)	113	104 (2.5)	122	111 (2.4)	>125
$\bar{X}$	89	86	96	104	105	113	107	>119	112	>122.2
s	7.8	10.1	7.4	8.9	8.6	8.6	10.5		12.1	

Table III. Example of data matrix at the estimation task, giving the number of times (maximum = 30) with which a certain sound pressure level (column) was judged as belonging to a certain loudness category (row). All vacant cells denote zeroes. The computation of limits corresponding to the "loudness labels" at the adjustment task is illustrated (note that half the number of judgements = 30/2 = 15).

	dB SPL											
Loudness category	55	65	75	80	85	90	95	100	105	110	115	120
Too soft	30	30	25	12	5							
Comfortably loud			5	18	25	20	14					
Too loud						10	16	27	2	1		
Discomfortably loud								3	28	17	8	
Painfully loud										12	18	10
Unbearably loud											4	20

Limit corresponding to loudness label 1 = $75 + \frac{10}{13} \times 5 = 78.8$ dB

" " " " " 2 = $90 + \frac{5}{6} \times 5 = 94.2$ "

" " " " " 3 = $100 + \frac{12}{25} \times 5 = 102.4$ "

" " " " " 4 = $110 + \frac{3}{10} \times 5 = 111.5$ "

" " " " " 5 = $115 + \frac{11}{16} \times 5 = 118.4$ "

Table IV. Mean values over subjects ($\bar{X}$) and standard deviations (s) of the individual means at the respective loudness label for the adjustment task and the estimation task at the original test and at the retest for subjects 6-7 and 9-11.

		Loudness labels									
		1		2		3		4		5	
		Adj.	Est.	Adj.	Est.	Adj.	Est.	Adj.	Est.	Adj.	Est.
ORIGINAL TEST	$\bar{X}$	83	87	97	104	103	>111	111	>117	120	>119
	s	9.4	8.9	7.1	6.5	7.6	6.8	7.3		7.5	
RETEST	$\bar{X}$	87	86	102	105	109	113	117	122	>125	>126
	s	11.6	11.7	4.0	4.0	6.4	4.4	6.4	4.6	5.0	

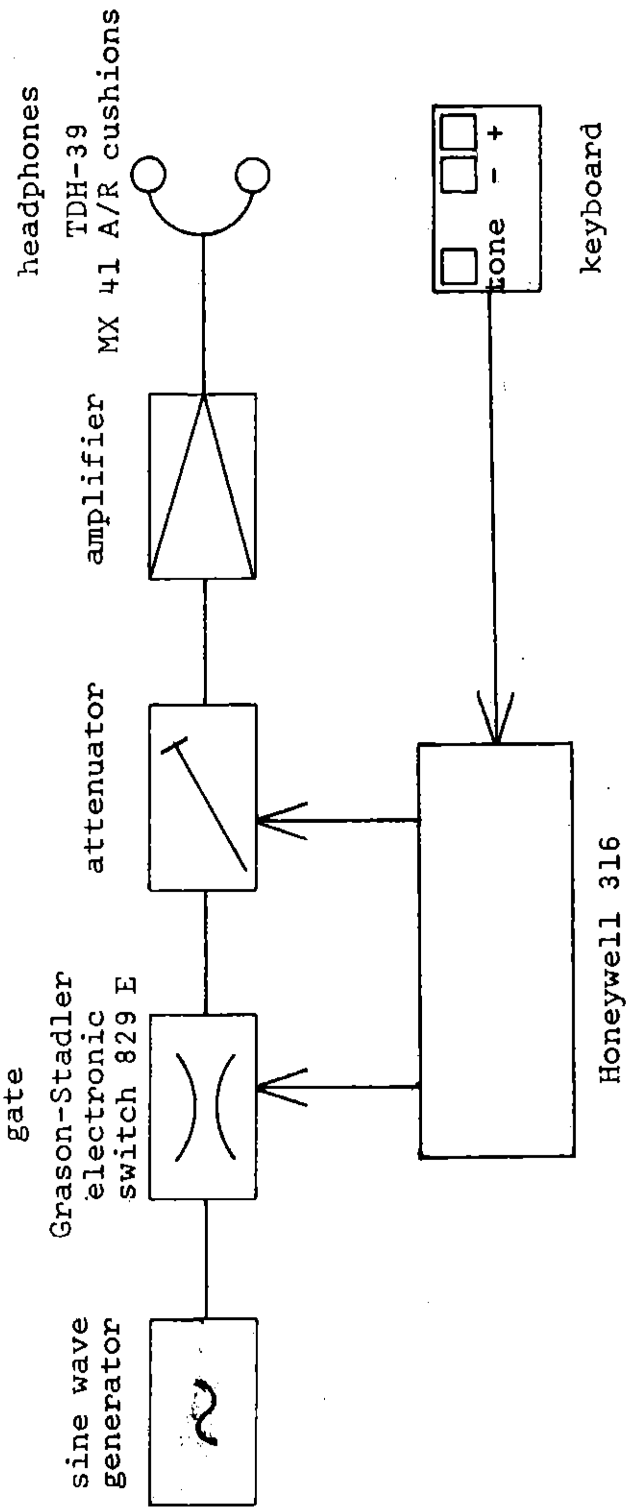
Fig. 1. Test equipment.

Fig. 2. Audiograms of six test subjects (subjects no. 13-18) with hearing loss.

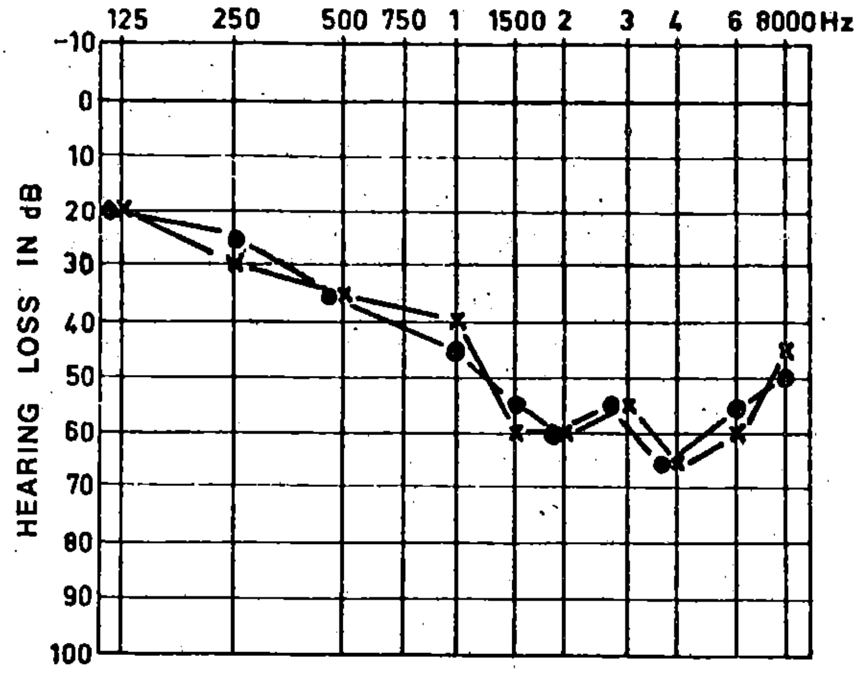
Fig. 3. Individual mean values (dB SPL) at five loudness labels for normal hearing subjects (subjects 1-12). For subjects 6, 7, 9, 10, and 11 also the results of the retest are given.

Fig. 4. Individual mean values (dB SPL) at five loudness labels for subjects with hearing loss (subjects 13-18). Designations as in Fig. 3.

Karolinska Institutet Teknisk Audiologi Stockholm	Test equipment	Fig. 1



SUBJECT: 13 FIG 2

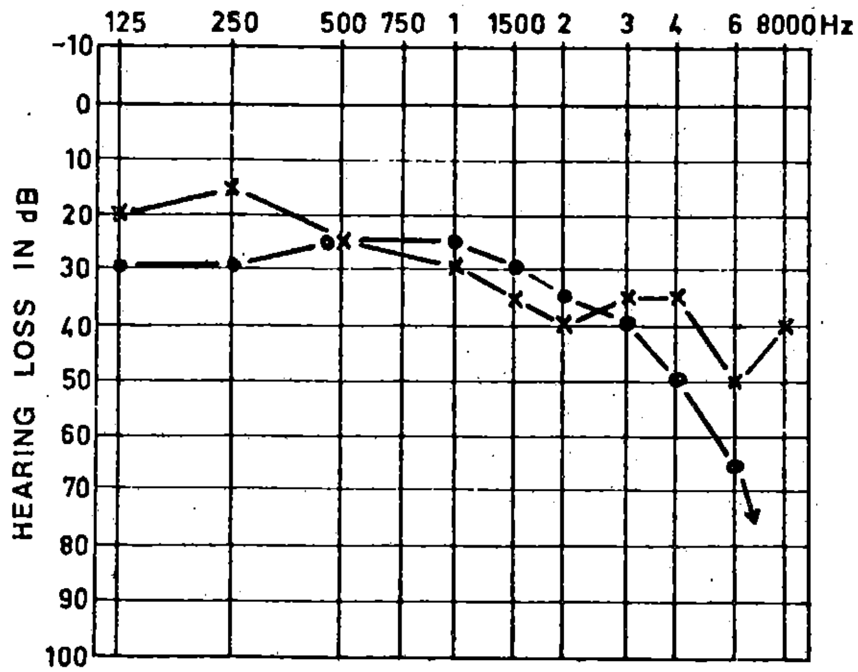


Age: 30 Suffering from early age

x——x LEFT EAR

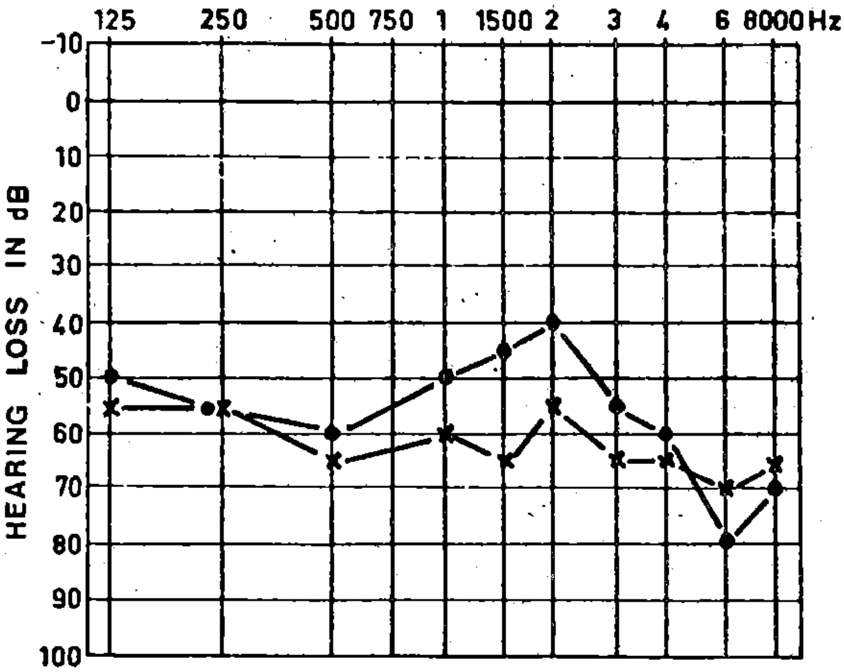
•——• RIGHT EAR

SUBJECT: 14



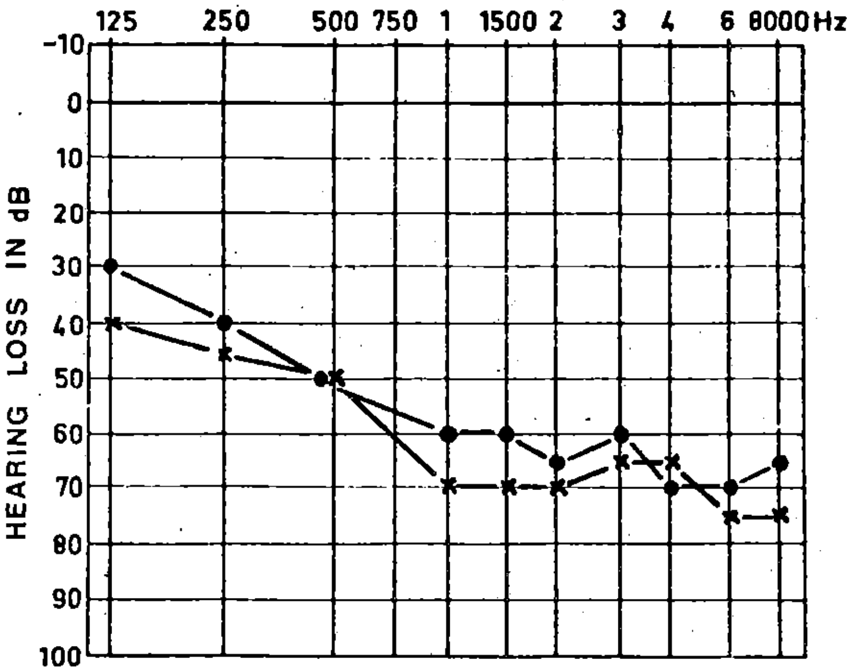
Age: 50 Suffering from the age of 43

SUBJECT: 15 FIG 2



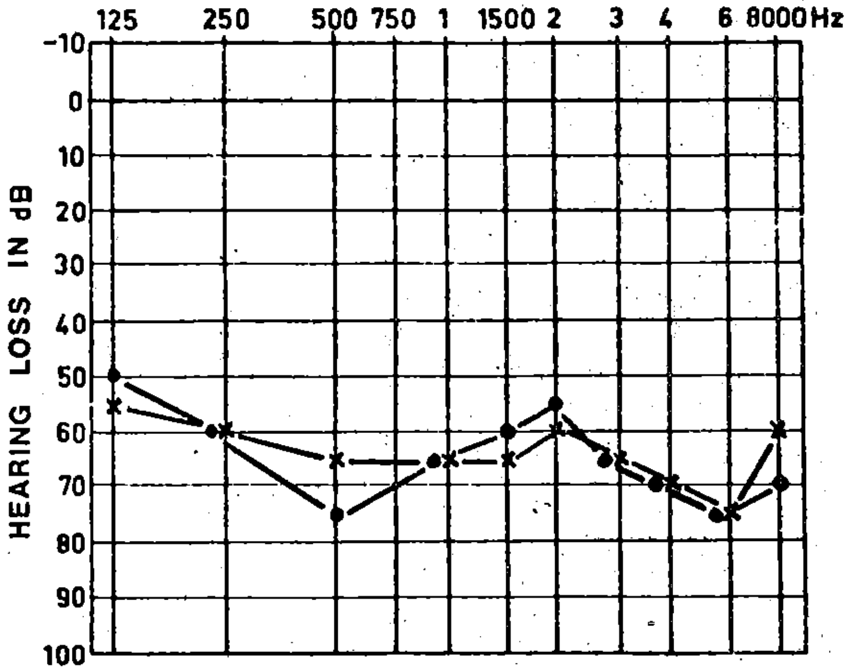
Age: 53 Suffering from the age of 43

SUBJECT: 16



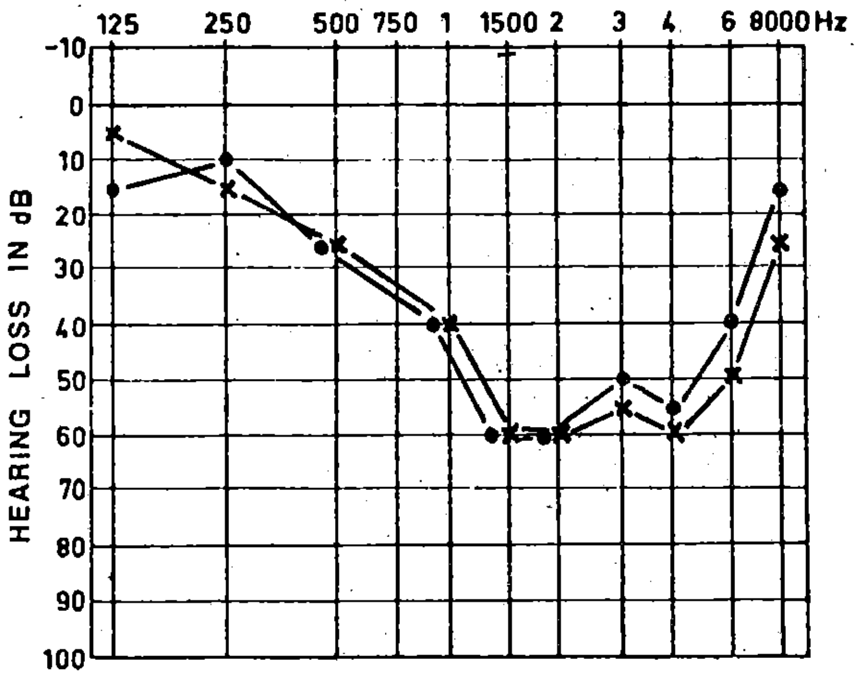
Age: 51 Suffering from the age of 20

SUBJECT: 17 FIG 2

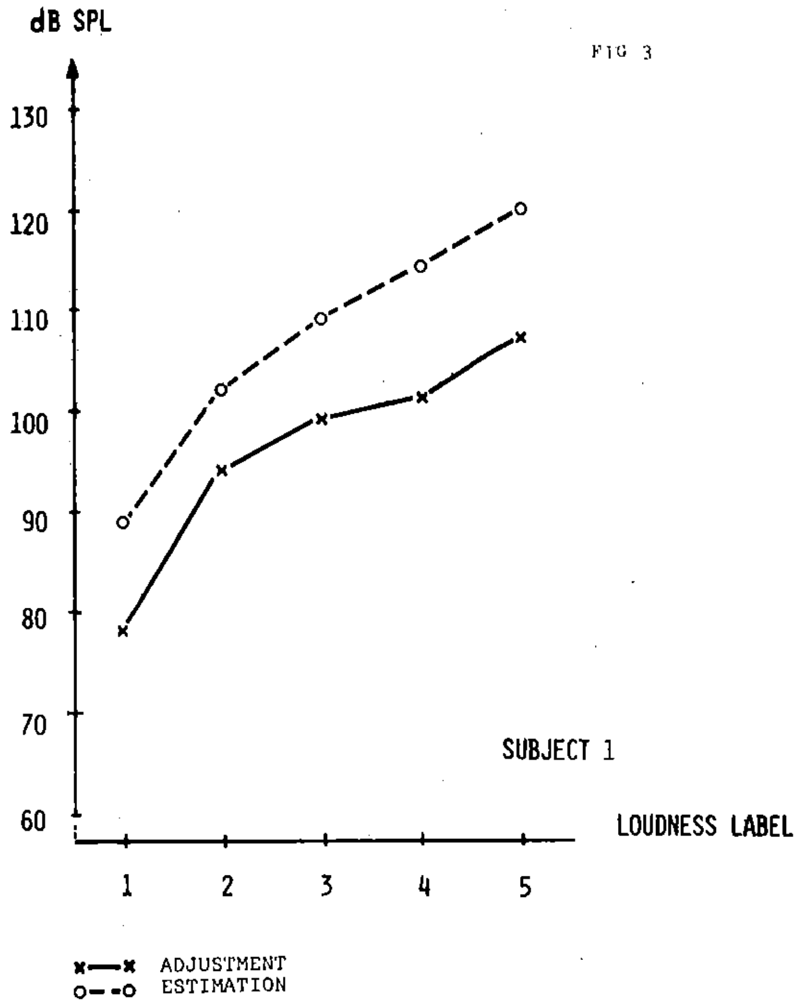


Age: 42 Suffering from the age of 15

SUBJECT: 18



Age: 33 Suffering from early age


dB SPL
FIG 3
130
120
110
100
90
80
70
60
SUBJECT 1
LOUDNESS LABEL
1
2
3
4
5
ADJUSTMENT
ESTIMATION

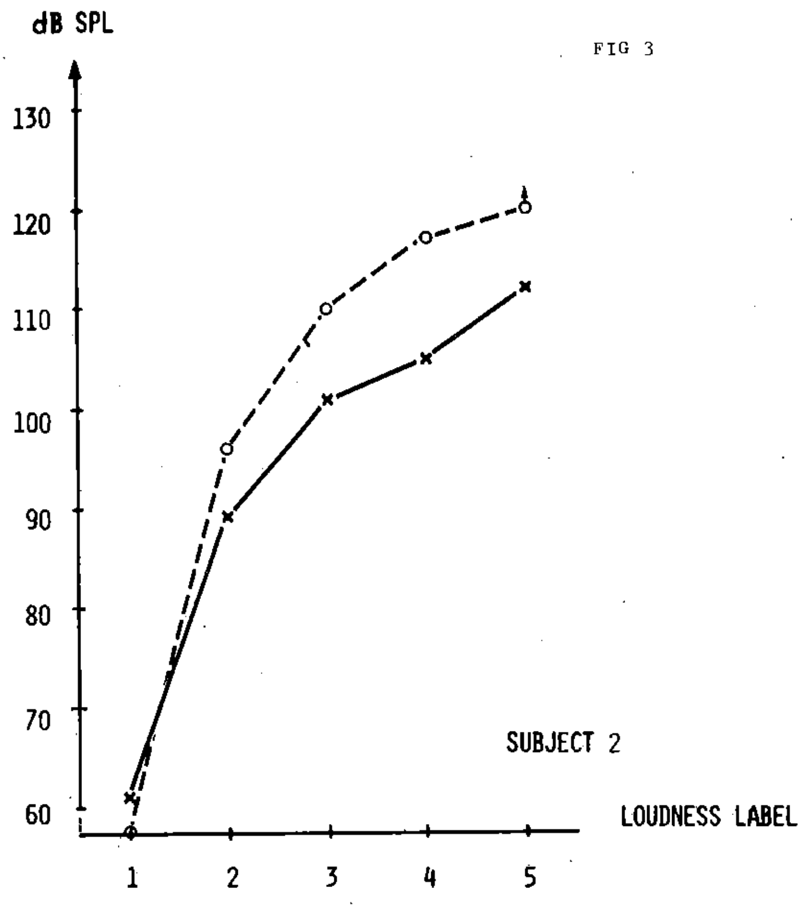

dB SPL
FIG 3
130
120
110
100
90
80
70
60
SUBJECT 2
LOUDNESS LABEL
1
2
3
4
5

FIG 3

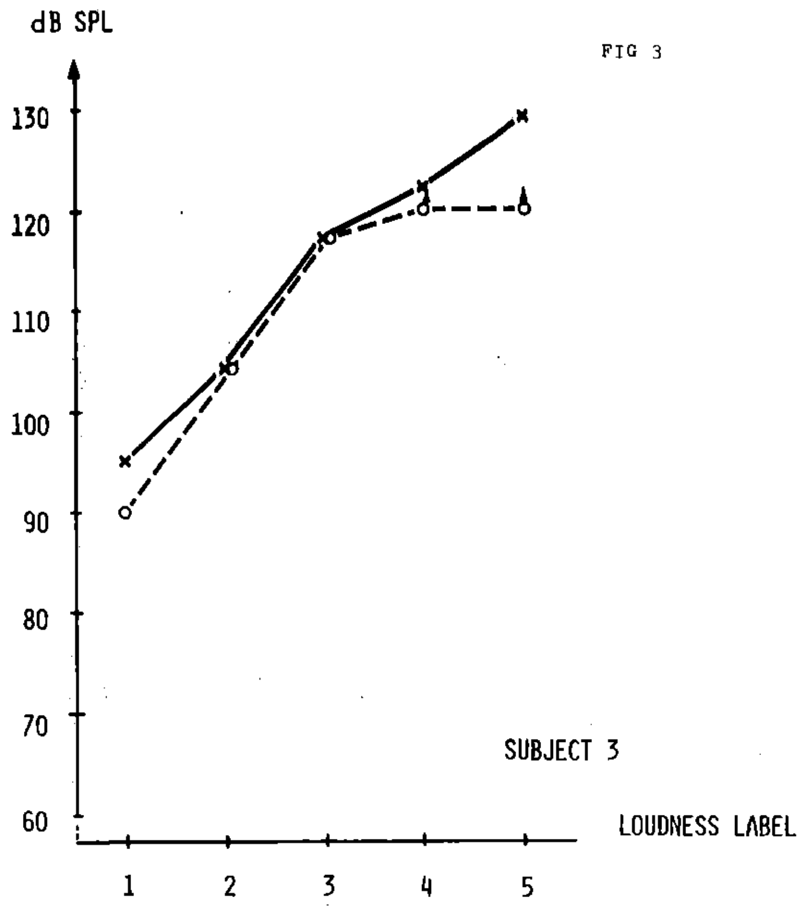

dB SPL
130
120
110
100
90
80
70
60
SUBJECT 3
LOUDNESS LABEL
1
2
3
4
5

FIG 3

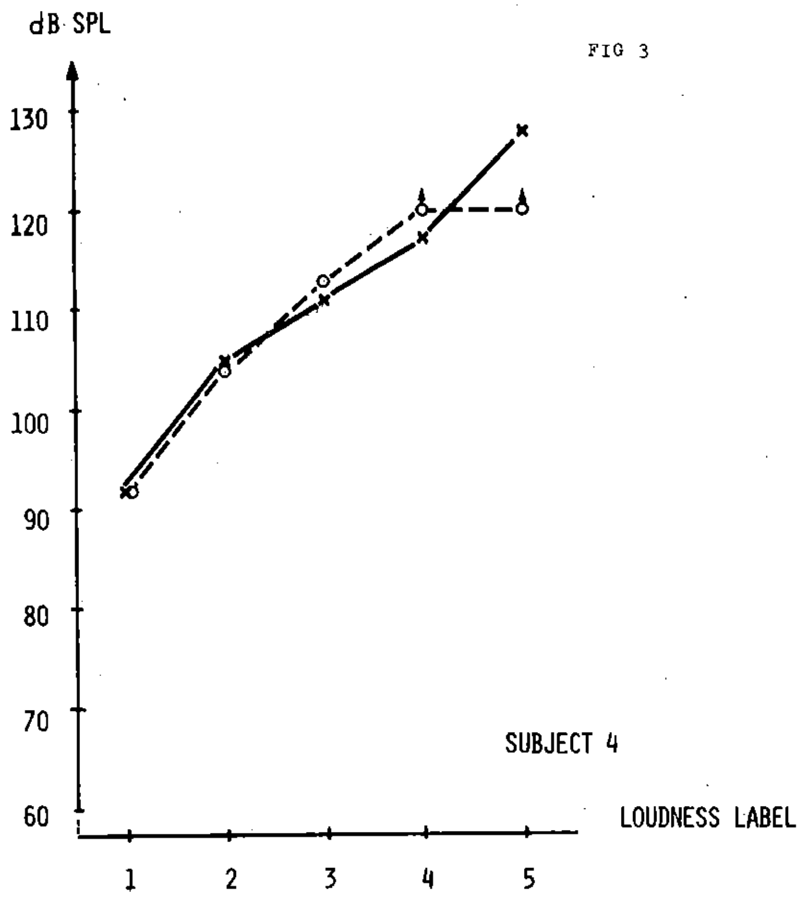

dB SPL
130
120
110
100
90
80
70
60
SUBJECT 4
LOUDNESS LABEL
1
2
3
4
5

FIG 3

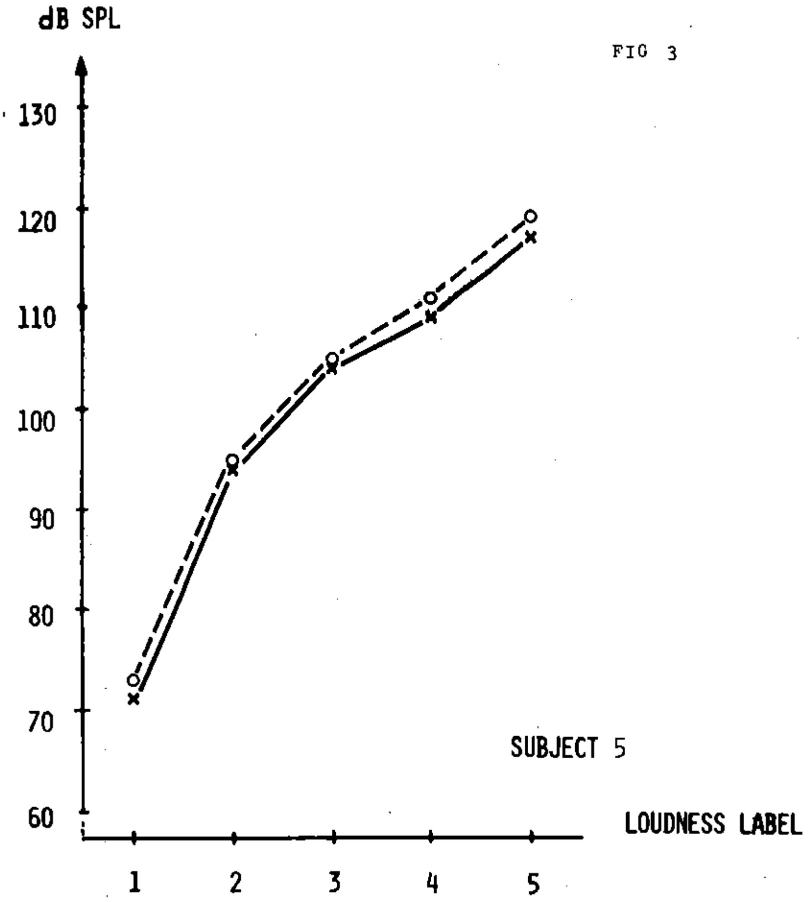
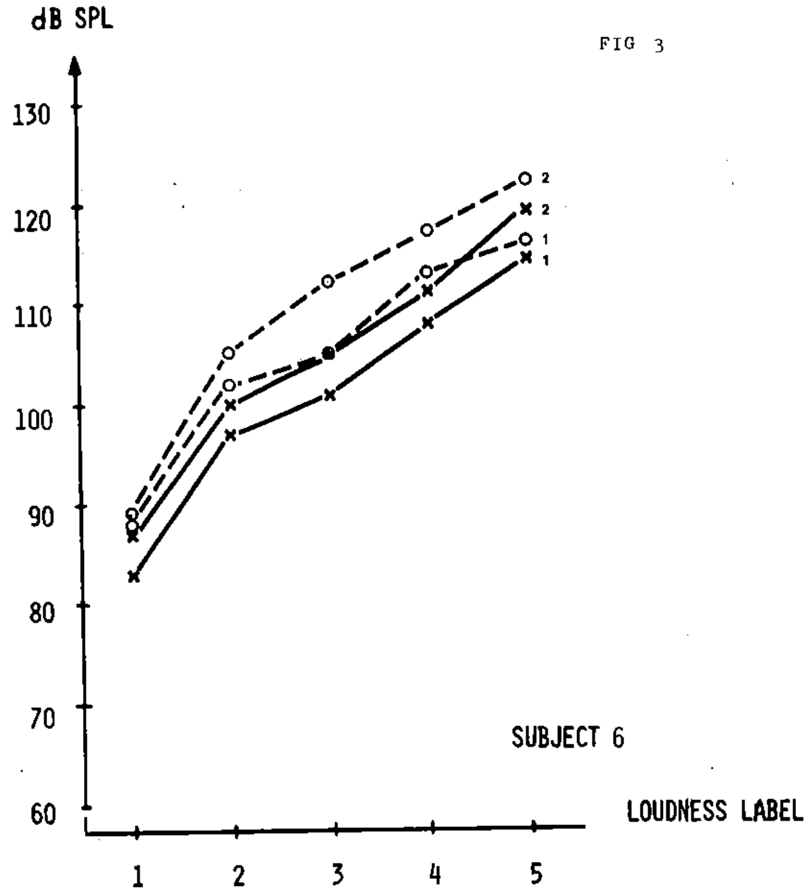


FIG 3



x——x 1 ADJUSTMENT ORIGINAL TEST
x——x 2 ADJUSTMENT RETEST
o—-o 1 ESTIMATION ORIGINAL TEST
o- -o 2 ESTIMATION RETEST

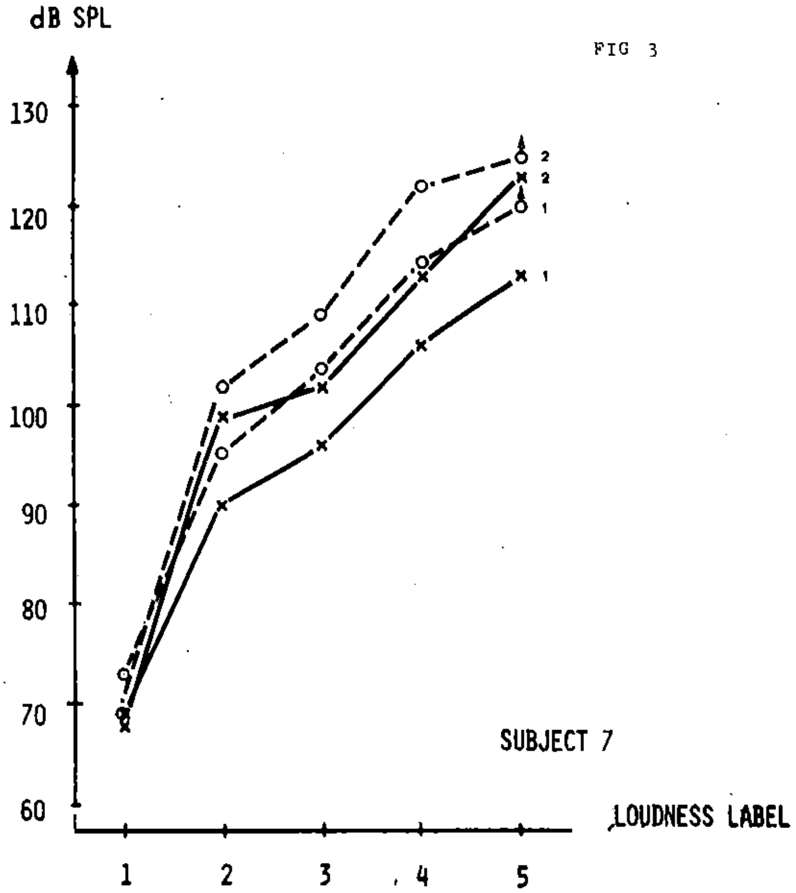

dB SPL
130
120
110
100
90
80
70
60
2
2
1
1
SUBJECT 7
LOUDNESS LABEL
1
2
3
4
5

FIG 3

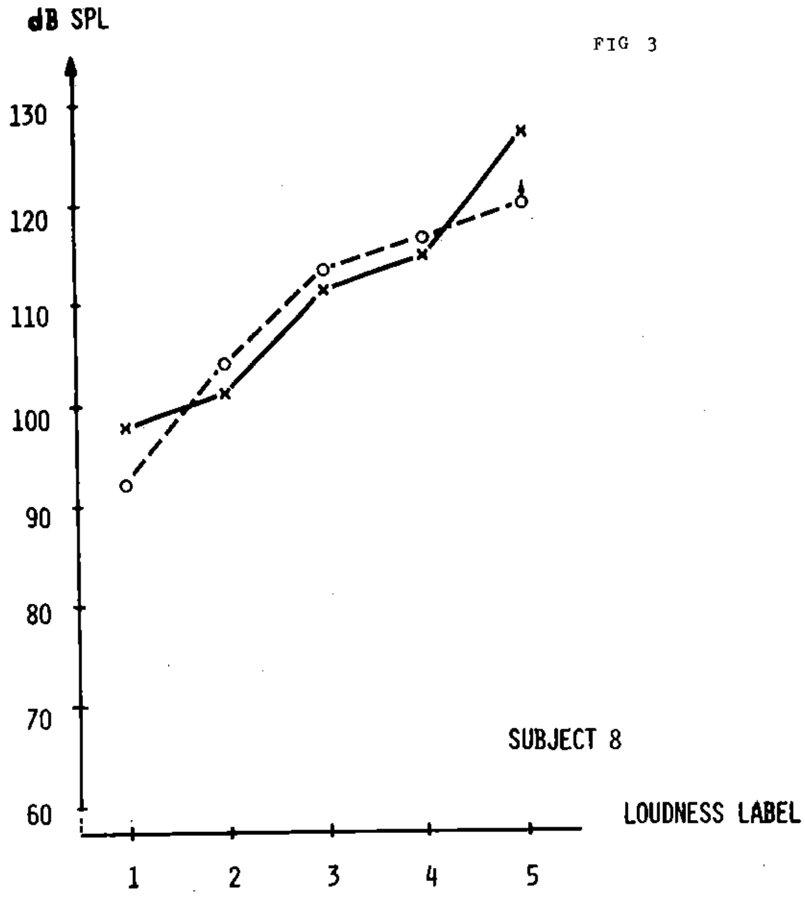

dB SPL
130
120
110
100
90
80
70
60
SUBJECT 8
LOUDNESS LABEL
1
2
3
4
5

FIG 3

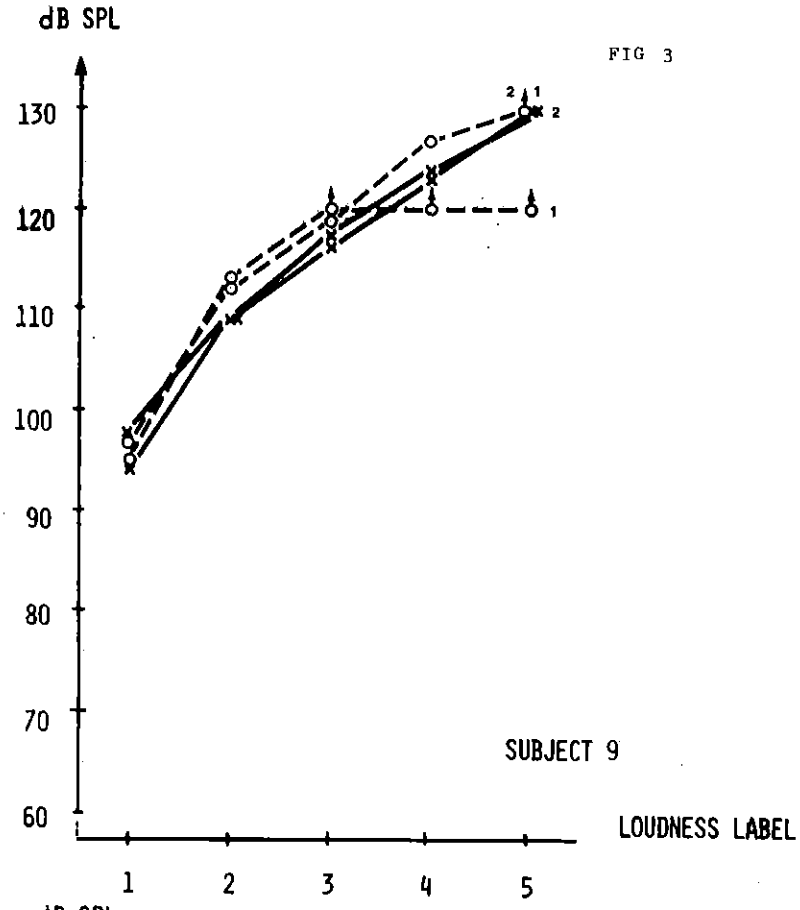

dB SPL
130
120
110
100
90
80
70
60
SUBJECT 9
LOUDNESS LABEL
1
2
3
4
5

FIG 3

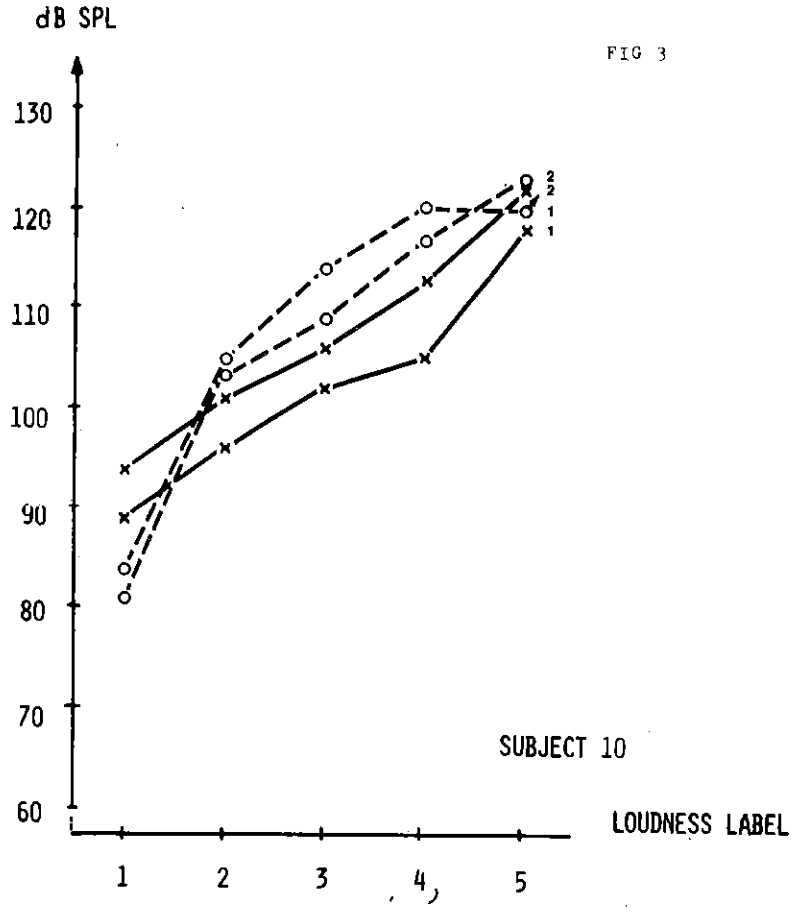

dB SPL
130
120
110
100
90
80
70
60
SUBJECT 10
LOUDNESS LABEL
1
2
3
4
5

FIG 3

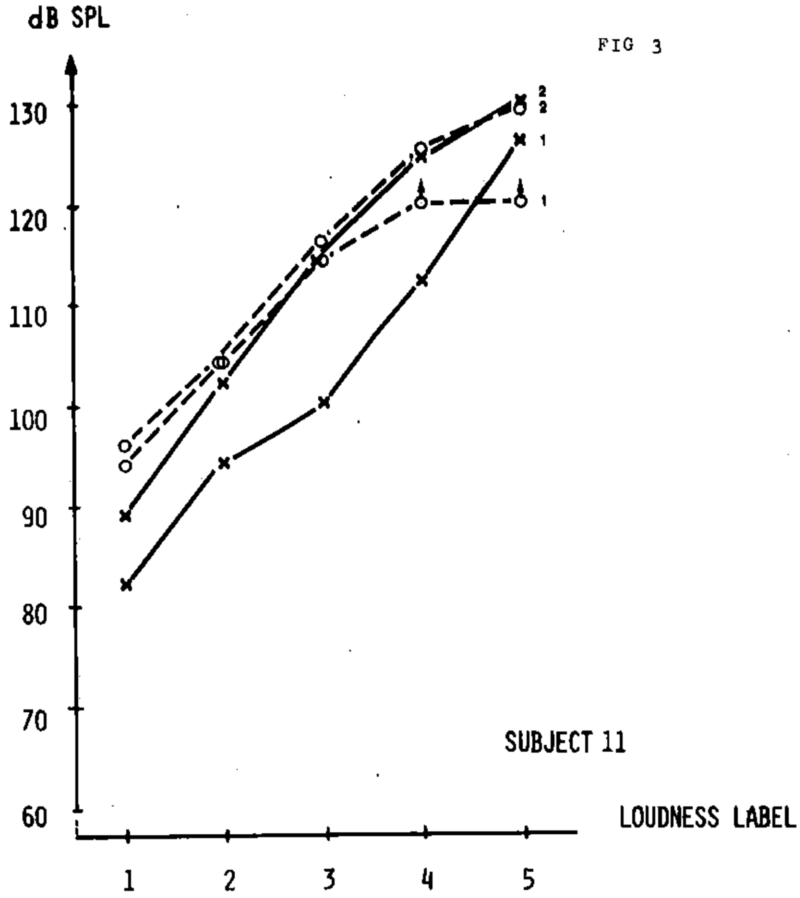

dB SPL
130
120
110
100
90
80
70
60
SUBJECT 11
LOUDNESS LABEL
1
2
3
4
5

FIG 3

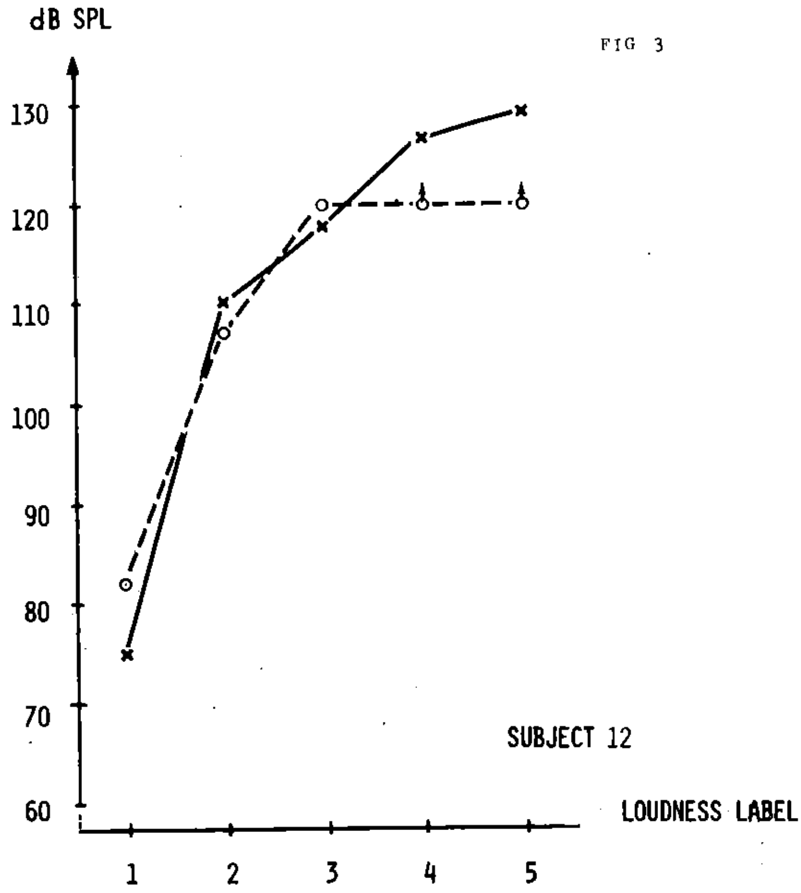
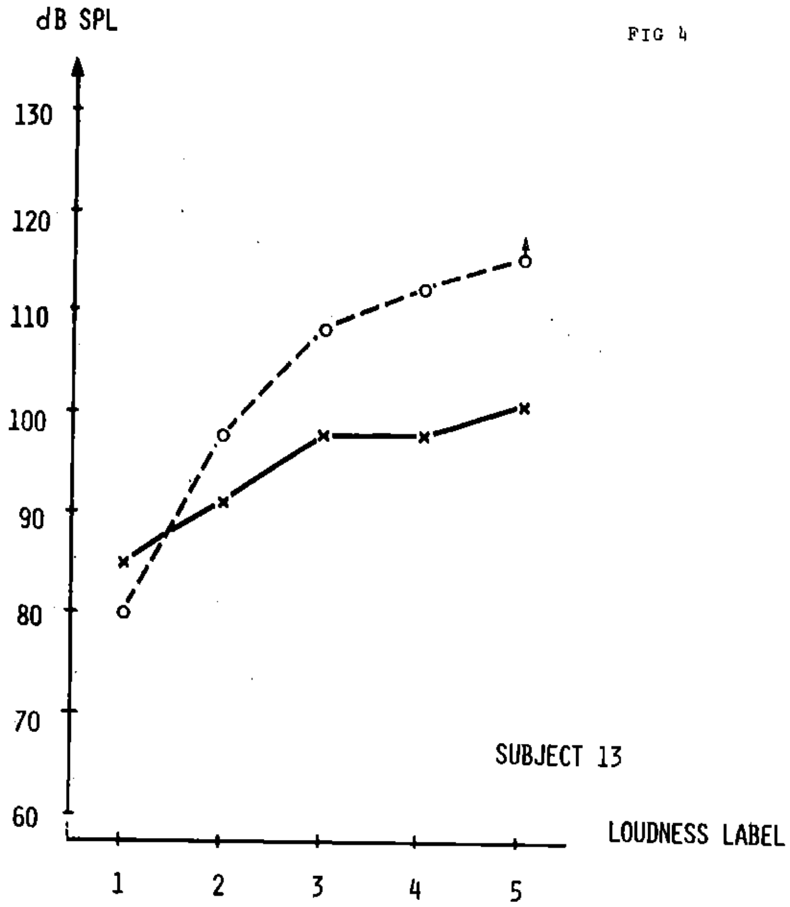

dB SPL
130
120
110
100
90
80
70
60
SUBJECT 12
LOUDNESS LABEL
1
2
3
4
5

FIG 4



x——x ADJUSTMENT
o–·–o ESTIMATION

FIG 4

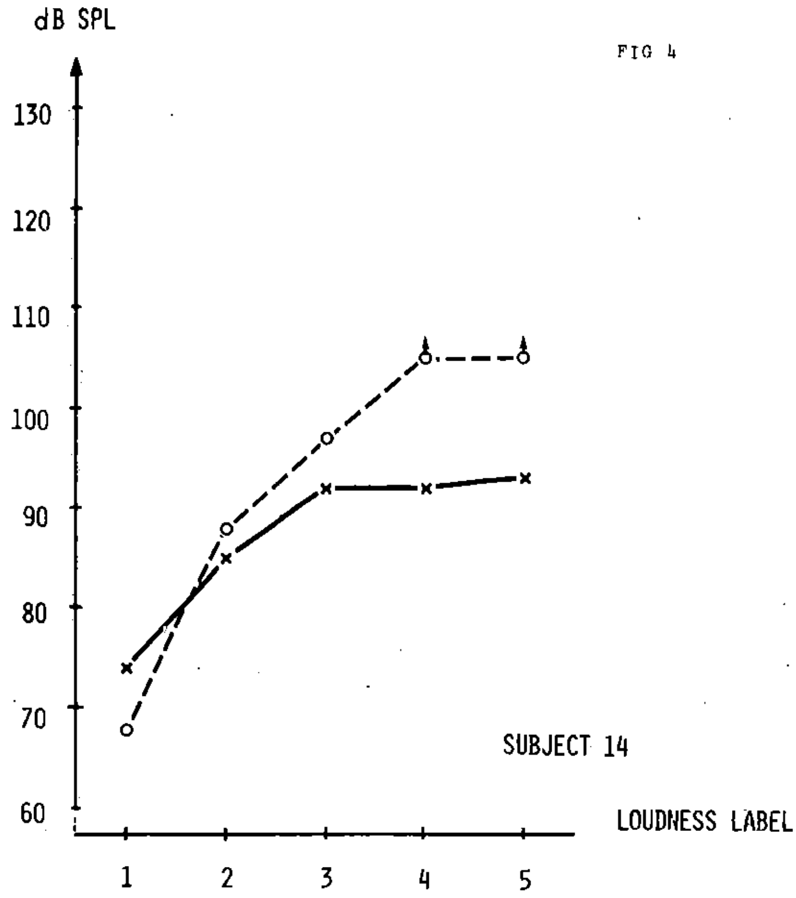


FIG 4

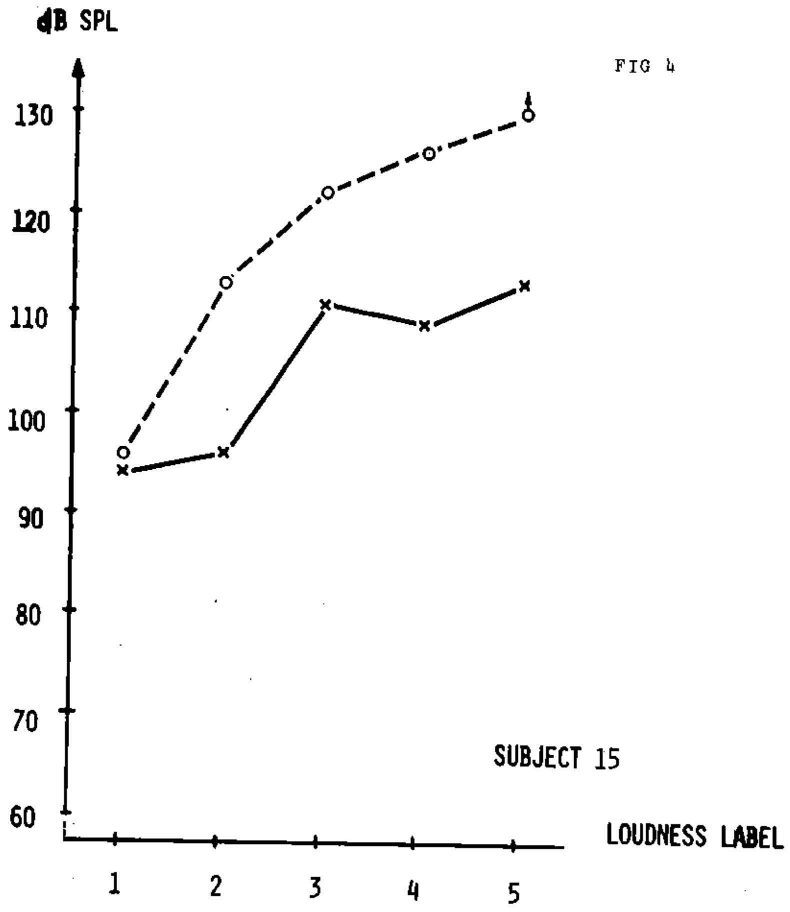

dB SPL
130
120
110
100
90
80
70
60
SUBJECT 15
LOUDNESS LABEL
1
2
3
4
5

FIG 4

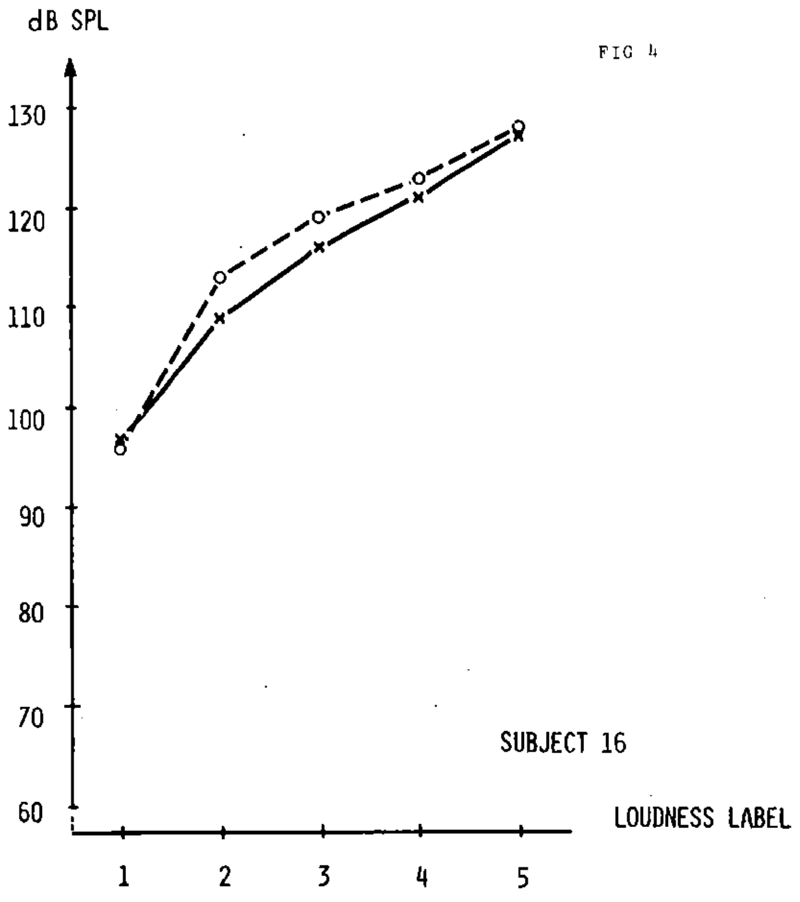

dB SPL
130
120
110
100
90
80
70
60
SUBJECT 16
LOUDNESS LABEL
1
2
3
4
5

FIG 4

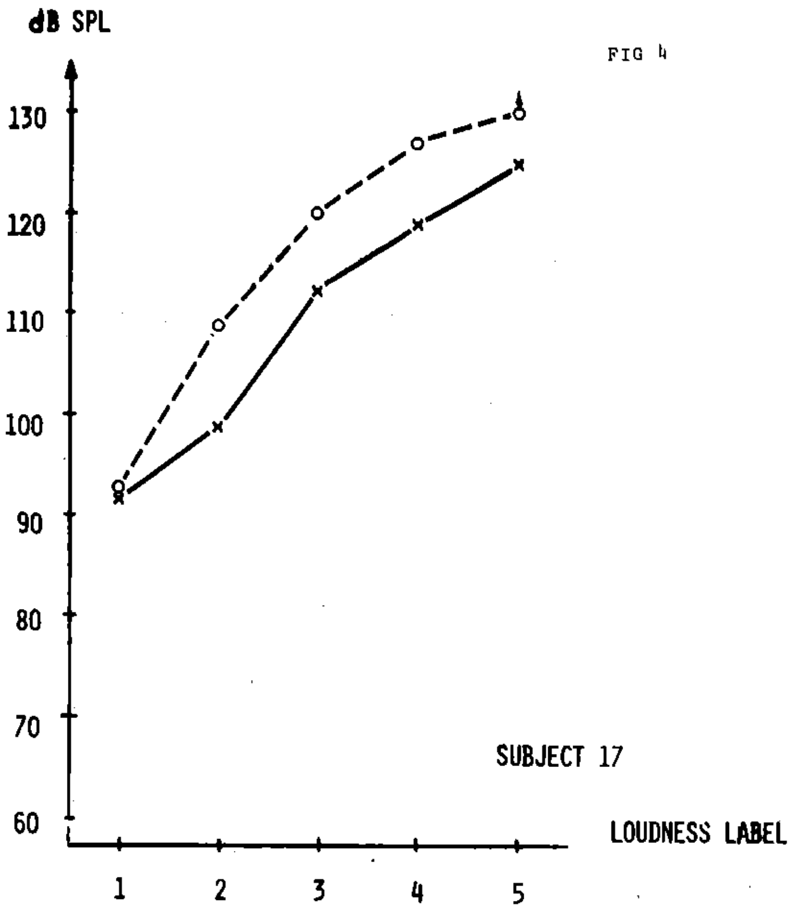
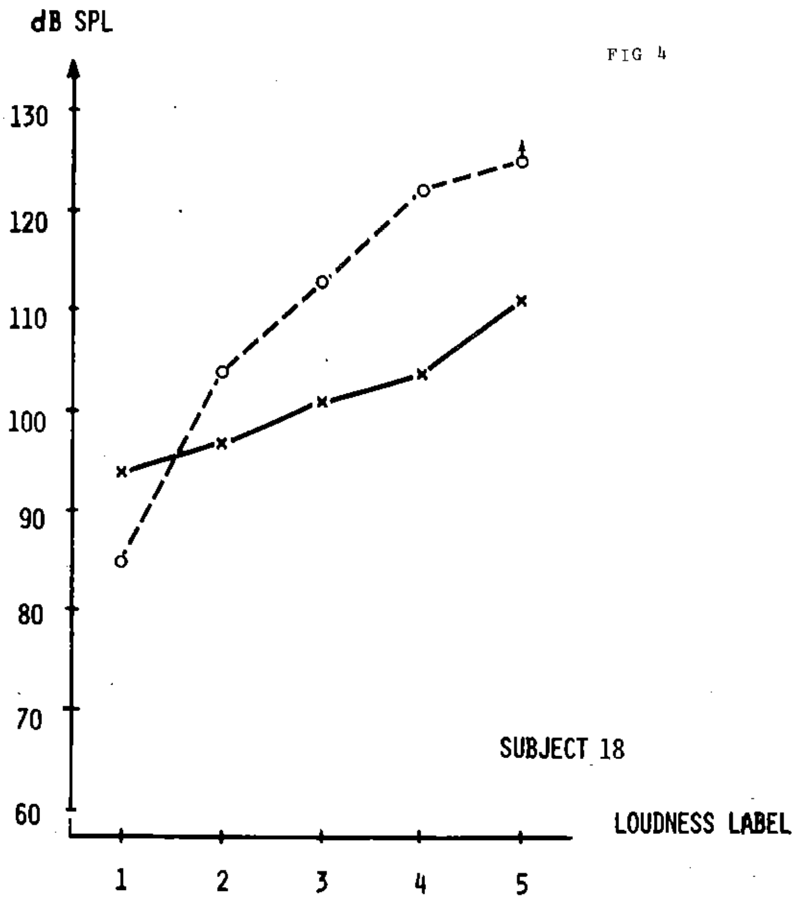

dB SPL
130
120
110
100
90
80
70
60
SUBJECT 17
LOUDNESS LABEL
1
2
3
4
5

FIG 4


dB SPL
130
120
110
100
90
80
70
60
SUBJECT 18
LOUDNESS LABEL
1
2
3
4
5