An experimental investigation of the phenomenon of auditory fatigue

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An experimental investigation of the phenomenon of auditory fatigue.

by

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ABSTRACT.

Auditory fatigue is now known as Temporary Threshold Shift (subsequently abreviated to TTS). It has been defined as the temporary elevation in the absolute threshold of hearing for a given test sound resulting from preceding auditory stimulation by a given stimulus sound (see Hirsh, 1952, page 177). Associated with the phenomenon there are six physical variables which sub-divide themselves into stimulus, test and recovery factors. In this study each of the latter factors was systematically investigated using four groups of six undergraduate subjects. Thresholds were measured using the Békésy (1947) technique of threshold measurement. Control experiments were carried out to verify that TTS results from the application of the stimulus tone, to study the mechanisms involved in the Békésy technique of threshold measurement and the effects of this technique on the measurement of TTS, to investigate any additive effects of TTS and to study the possibility of any measurement errors resulting from the physical test environment.

The results of the experiments showed that the stimulus, test and recovery factors all produced a consistent duality of results. It was concluded that the unitary definition of TTS is inadequate and that there are two TTS mechanisms. These are referred to as fatigue and temporary stimulation deafness. Fatigue is associated with moderately intense stimulus tones of fairly short duration. It increases linearly with logarithm of the stimulus duration; it is maximal at stimulus frequencies of 1000, 2000 and 3000 cps; it does not vary significantly with stimulus intensities of up to 90 db. but thence increases rapidly to a maximum; it is maximal at a test frequency equal to the stimulus frequency and recovery from it is complete within one minute of the cessation of the stimulus. Temporary stimulation deafness is associated with high intensity stimulus tones of fairly long duration. It increases linearly with the logarithm of the stimulus duration; it is maximal with stimulus frequencies of 4000 to 6000 cps; it increases rapidly as the stimulus intensity is increased; it is maximal at a test frequency an octave above the stimulus frequency and recovery from it takes longer than one minute

from the cessation of the stimulus tone.

It is hypothesized that fatigue is a neural, possibly bio-chemical, adaptation effect and that temporary stimulation deafness results from structural damage to the organ of Corti. Other work supports this differentiation. The phenomena of fatigue support either a "place" or a "volley" theory of hearing. The phenomena of temporary stimulation deafness are partially explicable in terms of the anatomical characteristics of the ear.

PART 1.

PREVIOUS WORK.

CHAPTER 1.

INTRODUCTION.

Auditory fatigue may be defined as the temporary elevation in the absolute threshold of hearing for a given test sound resulting from prior stimulation of the ear by a suitable stimulus sound (see Hirsh, 1952, page 177). Unfortunately, the term has many theoretical implications and consequently in the past ten years the term auditory fatigue has been replaced by the term Temporary Threshold Shift (TTS, see Meyer, 1953). TTS is not to be confused with Hood's "perstimulatory fatigue", i.e. "adaptation" (see Hood, 1950 and Bocca, 1960). The latter phenomenon is a temporary elevation of the threshold of hearing resulting during the application of a suitable stimulus tone. It is closely associated with physiological adaptation and Hood suggests that it is localised in the end-organs of the organ of Corti. It is also closely associated with the transient threshold shifts caused by very short duration stimuli such as those used by Luscher and Zwislocki (1947). Stimulation deafness (see Caussé and Chavasse, 1942-43) is another phenomenon closely associated with TTS. However, stimulation deafness is a permanent elevation in the threshold resulting from exposure to preceding auditory stimulation.

Figure 1 illustrates the general procedure followed in experiments on TTS. It can be seen that there are three main stages as follows :

(i) The application of a given test sound to determine the pre-stimulus, i.e. the pre-exposure, threshold.

(ii) The application of the stimulus sound, i.e. the exposure period.

(iii) The re-application of a given test sound to determine the post-stimulus, i.e. post-exposure, threshold.

The difference between the post-exposure and the pre-exposure thresholds provides an operational measure of TTS. Further inspection of figure 1 reveals that within the TTS situation the stimulus, test and recovery factors are associated with six physical independent variables. These are :

(i) The frequency or type of stimulus sound.

(ii) The intensity of the stimulus sound.

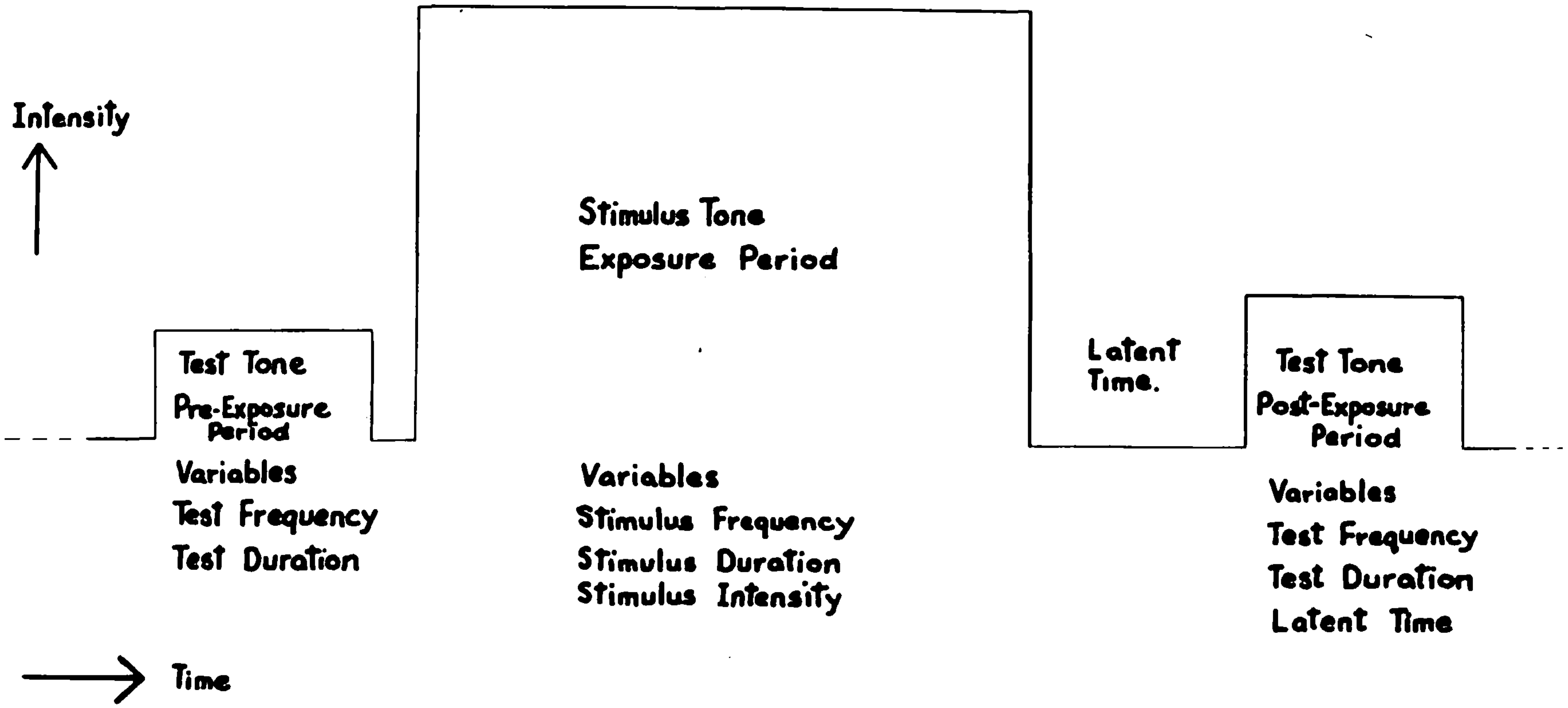


Figure 1: Illustrates the proceedure and main parameters involved in TTS experiments.

(iii) The duration of the stimulus sound.

(iv) The time after the cessation of the stimulus sound at which the post-exposure threshold is measured (i.e. latent time, see Rodda, 1960).

(v) The frequency or type of test sound.

(vi) The duration of the test sound.

The duration of the test sound in TTS experiments is usually fairly long or continuous, since variations in threshold with test sound duration are thought to result from changes in the test duration and not from any TTS effects. Since the advent of the Békésy technique of threshold measurement in 1947 (see Békésy, 1947) this has been used almost exclusively for making threshold measurements in TTS experiments. The technique enables the subject to determine his own threshold by varying the intensity of a sound and consequently very rapid determinations of his threshold can be made. Since the threshold shifts resulting from TTS are only temporary, this ability to measure rapidly the threshold is of obvious advantage. Unfortunately, since the method is comparitively new, knowledge of its psychological basis is very limited.

The first experiments on TTS were probably carried out by Urbantschitch (1875). Since that date papers have regularly appeared on the topic. In the majority of these papers, testing has been usually limited to showing the effect of one variable under very specific conditions. Consequently, the results obtained are not general and a combination of the results from different experiments to provide an overall picture is virtually impossible. Hirsh (1952, page 178) refers to "the disjointed and apparently unrelated nature of the parts" of the problem that have been studied. In 1962 the position is little better. There are three exceptions to the statement made above. Hood (1950) has published a fairly extensive study of the problem. He used moderately intense stimulus tones of moderate durations. However, in the majority of his experiments, he only used one stimulus condition. Davis, Morgan, Hawkins, Galambos and Smith (1950); Ward, Glorig and Sklar (1959) and Ward, Glorig and Selters (1960) have published very extensive work on TTS effects resulting from very intense stimulus tones applied for long periods. However, as will be shown in subsequent sections these intense exposures to not produce a TTS similar to that produced by more moderate exposures.

It can be concluded that there is a grave lack of continuity in the study of TTS resulting from moderately intense stimuli and a failure to differentiate this effect from TTS resulting from more intense stimuli. The experiments reported in this thesis are an attempt to begin inter-relating all of the TTS variables. The experiments are not complete and it will require many more years of intensive study before the vast range of possibilities has been studied. However, they do cover the effect of variation of the stimulus and test conditions both seperately and concurrently.

CHAPTER 11

HISTORY.

The history of TTS is found to be intimately interlinked with the more general problem of fluctuations in sensory responses or as it has since become known the "fluctuations of attention" controversy (see Oldfield, 1955). In 1875 Urbantschitch (1875) published a paper describing changes in the response of a subject to simple sound stimuli. This reported that weak sound stimuli which were of a constant intensity around threshold level, such as the ticking of a watch, were irregularly detected by the observers. Physical variations in the actual intensity of the sound did not give rise to the effect since a careful control experiment showed that different subjects reported not hearing the sounds at different times. Urbantschitch explained the observations in terms of a dual fatigue and recovery process within the auditory nerve. Thus the concept of auditory fatigue or TTS entered into the terminology of psycho-acoustics.

However, the next fifty two years saw a major conflict of opinion as to whether the auditory mechanism could be fatigued or whether Urbantschitch's and similar results were simply an artifact of attentional factors. Thirteen years after the publication of Urbantschitch's paper Lange (1888, see Guildford, 1927) rejected the hypothesis of fatigue because :

(i) There is no evidence that sensory nerves tire so quickly from minimal stimuli.

(ii) "The nerve would have to recover while being stimulated".

(iii) "The effect ought to be noticed with intense stimuli".

Lange conducted experiments in which he found that when two stimuli from two modalities were presented simultaneously they did not fluctuate independently but formed a rythmn in which one stimulus alternated with the other. Hence, he concluded the phenomenon resulted from "fluctuations of attention" which gave rise to corresponding fluctuations in the "apperceptive" process.

It is at this point in history that the problem of auditory fatigue became subordinate to the problem of whether there are real variations in the threshold resulting from fatigue, adaptation or some other similar phenomenon or whether such changes are merely the result of attentional irregularities. With the posing of this more general problem, the study tended to leave the field of audition and auditory fatigue and concentrate on other sensory modalities. Possibly due to the influence of Wundt and the Wurzburg School, vision tended to predominate as the most prolific field of study. Supporters of the "fluctuations of attention" explanation of threshold variations with auditory or other sensory stimuli included Slaughter (1901), Pillsbury (1903) and Galloway (1904). Supporters of the adaptation or fatigue theories included Lehmann (1894), Munsterberg (1889), Heinreich and Chwisteck (1907) and Ferree (1906 and 1908).

During the middle of the "fluctuations of attention" controversy there developed a minor controversy as to whether or not there were in fact any true fluctuations of perceptual responses to auditory stimuli. Huijsman (1894), Heinreich (1900 and 1907), Hammer (1905) and Schaeffer (1905) found no evidence for such fluctuations, whereas Cook (1900), Titchener (1901), Wiersma (1901), Bonser (1903), Dunlap (1904) and Seashore and Kent (1905) did. However, Jackson (1906) observed that the range of intensities over which fluctuations are observed is very small. Hence it seems probable that the negative results were associated with the use of stimuli which were outside the range in which Jackson observed the effects to occur.

It was not until 1927 when Pattie (1927) published an excellent paper on the topic that auditory fatigue became an established fact and, the hypothesis of "fluctuations of attention" as a general explanation of all threshold variations fell into disrepute. The rout started by the publication of Pattie's paper was completed by the independent publication in the same year of a paper by Guildford (1927) specifically on "fluctuations of attention".

Prior to the publication of Pattie's paper the general conclusion of most of the work following upon Urbantschitch's original paper was that the ear could not be fatigued. Huijsman (op.cit.), Sewall (1907), Schaeffer (op.cit.) and Bartlett and Mark (1922) all obtained negative

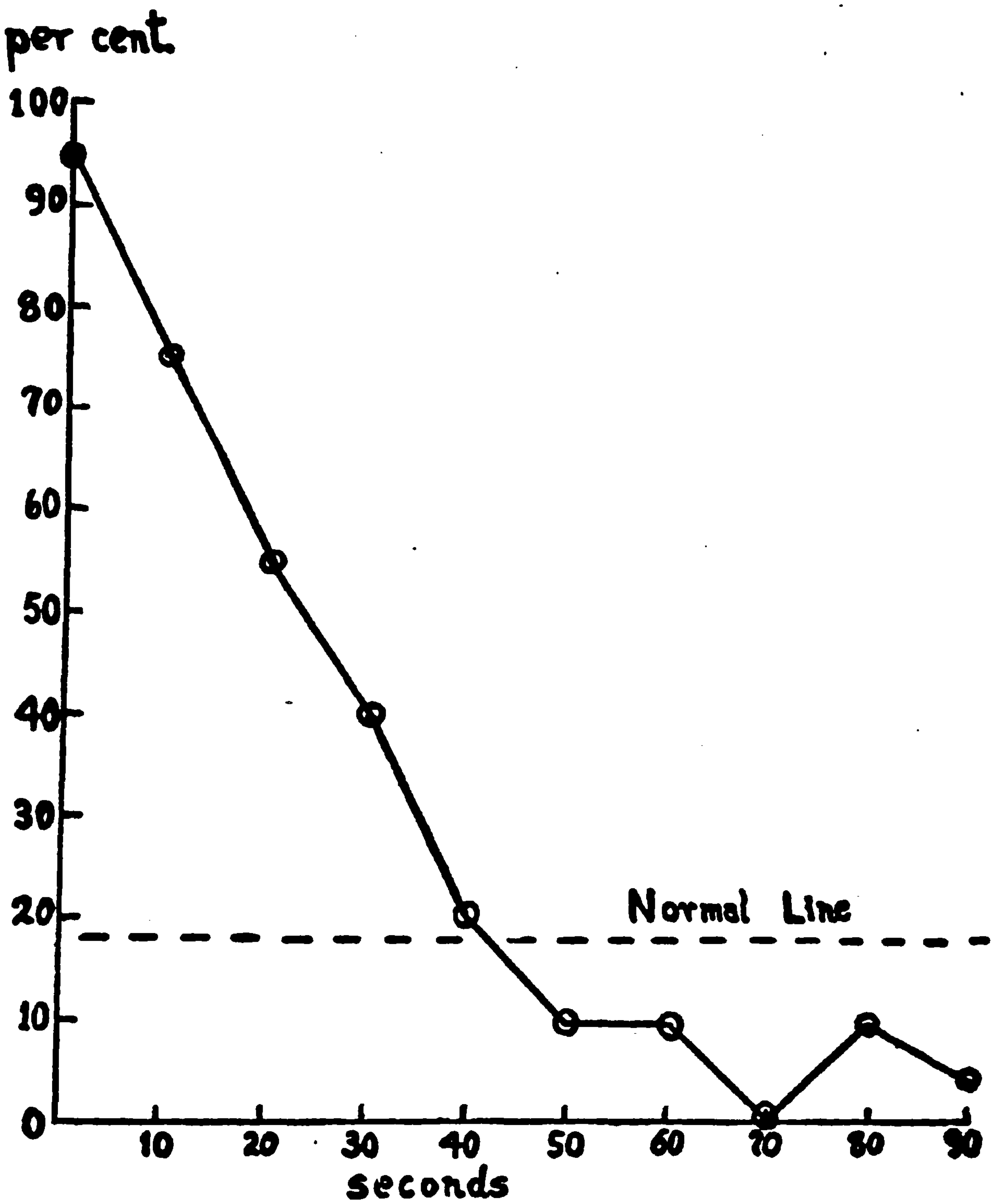


Plate 1.

Illustrates the results obtained by Pattie (1927). Abscissa is latent time in seconds. Ordinate is percent of responses judged louder in non-fatigued ear.

results. The positive results of other experimenters such as Wilson and Myers (1908), Albrecht (1919) and Flugel (1914 and 1920) were explained away as resulting from "fluctuations of attention." The difficulty of most of the early workers seems to have been one of finding an adequate and reliable measure of fatigue, i.e. a measure which suitably reflected changes in hearing acuity. Without exception they used sound stimuli well above threshold and used either changes in localization or changes in the time for which sound from a tuning fork was heard as measures of the effect. The difficulties with these methods and the criticisms that can be made in retrospect are that :

(i) Above threshold sounds are not likely to show fatigue effects as easily as sounds at or very close to the threshold.

(ii) Localization of sound stimuli tends to be accurate only for gross changes.

(iii) It is difficult to equate the loudness of tuning forks and hence to quantify the time for which a sound is perceived.

(iv) Unless a masking stimulus is applied to the contralateral ear there is often binaural stimulation when a tuning fork is placed on the mastoid process.

However, Pattie used a binaural loudness balance test to measure the changes in loudness resulting from monaural stimulation of the ear by pure tones and this proved to be a more sensitive measure.

The general form of Pattie's results are shown in plate 1 which is reproduced from his paper. He reached the conclusion that the ear could be fatigued but that the term "labile" used by Flugel (op. cit.) adequately described the phenomenon. A further control experiment using binaural stimulation indicated that the locus of fatigue was peripheral. Guildford stated that the problem "is nothing more than a matter of limen; to discover ways in which the phenomenon is dependent upon the intensity of the stimulus, to point out the operation of certain peripheral and central physiological factors." He used visual stimuli to study the phenomenon and avoided adaptation by utilizing only extremely brief presentations of the stimuli. He found that only with the latter condition did the intensity at which the stimulus was perceived for 50% of presentation time agree with the threshold as determined by the method of limits. In a series of carefully controlled experiments he found that retinal adaptation, eye movements and local central fatigue all affected the period for which the stimuli were perceived. He justifiably concluded that there are too many "physiological conditions" involved in the effect to attribute it to "fluctuations of attention."

Following on from Pattie's work several papers were published establishing the fact that appropriate preceding auditory stimulation has a "fatiguing" effect on the ear. Békésy (1929) found that fatigue was maximal at the frequency of the stimulus tone. Using stimulus tones of 200 to 2000 cps at an intensity of 100 db., he found that fatigue was produced at test frequencies of 1000, 2000 and 3000 cps. He also found that threshold shift was maximal at a stimulus/test frequency of 3000 cps and reached the erroneous conclusion that fatigue is not caused by stimulus frequencies of less than 1000 cps. More recent work (see Hughes, 1954) has shown that frequencies of less than 1000 cps will produce TTS.

Ewing and Littler (1935) extended the range of stimulus conditions covered by studying the effects of stimulation at intensities just below the threshold of pain. They used both normal and partially deaf subjects and found that the loss of sensitivity ranged over one or two octaves but that outside this range the threshold remained normal. They also found that fatigue increased as the duration of the stimulus was increased. Finally, they were the first workers to suggest that there might be more than one kind of fatiguing process.

Another line of investigation followed in this period was the effects of preceding auditory stimulation on the differential threshold of audition. Rawdon-Smith and Sturdy (1939) found that " a loss of differential sensitivity" for intensity resulted from preceding pure tone stimulation. They studied the characteristics of the effect and found that it was greatest at the stimulus frequency. They also found that only frequencies which were an even multiple of the stimulus frequency were affected. This line of research was again allowed to lapse and it was not until 1962 that further work was carried out on the phenomenon. Elliott, Riach and Silbiger (1962) found that as the amount of fatigue, that is as the severity of the exposure, was increased the differential threshold for intensity was reduced. This they explain as the result of recruitment which is often associated with fatigue and which causes an abnormal growth in the perception of loudness. (See Dix, Hallpike and Hood, 1948 and Hallpike and Hood, 1951).

The results of Elliott et al. are at first sight contradictory to the earlier results of Rawdon-Smith and Sturdy. However, a reconsideration of Rawdon-Smith and Sturdy's data indicates that the difference is partly one of emphasis. They emphasized the elevation of the differential threshold with increasing stimulus intensities but at a constant stimulus duration of two minutes. Elliott et al. emphasized the decrease of the differential threshold at approximately constant intensities of 105-115 db. but at varying stimulus durations which were arranged to produce increasing amounts of fatigue. Hood (op. cit.) has shown that the amount of fatigue increases only very slightly as the stimulus intensity is increased up to about 90 db. Rawdon-Smith and Sturdy used stimulus intensities ranging from 0 to 110 db. and thus we can assume that the amounts of fatigue produced by their stimuli were relatively constant for the lower stimulus intensities. Hence we can conclude that Rawdon-Smith and Sturdy's results indicate that with constant amounts of fatigue, the differential threshold for intensity increases in value as the stimulus intensity is increased. The results of Elliott et al. directly indicate that with increasing amounts of fatigue, the differential threshold for intensity is reduced. However, this difference only resolves the differences between different stimulus conditions. It does not resolve the basic differences between the two studies of quantitative increases or decreases re normal threshold. Unfortunately, Elliott et al. do not seem to have been aware of Rawdon-Smith and Sturdy's results and did not carry out any experiments with varying intensities. In the light of present knowledge it would appear that the results of Elliott et al. are more logical since they are supported by the recruitment phenomenon. However, more work is required in this field.

Initially Rawdon-Smith (1934) returned to the original fatigue hypothesis of Urbantschitch (op. cit.) and explained the phenomenon in terms of increases in the refractory period of the nerve fibres and a consequent reduction in the rate of volleying. In a later paper (Rawdon-

Smith, 1936) he changed the locus of the effect to a central mechanism because of results showing the existence of a "disinhibitory phenomenon." Thus if an innoccuous stimulus was applied to the subject during recovery from fatigue then there was an almost immediate return of the threshold to normality followed by a further increase in the threshold. Broadbent (1955) has pointed out that this result poses an unanswered question in work on TTS. It is now generally accepted that fatigue is peripheral but as yet nobody has explained how Rawdon-Smith's results can be explained on this basis. Unfortunately, the experiment has never been repeated and it does appear to have been omitted from any discussions of the locus of fatigue. However, it indicates that overlaying the peripheral locus there may be under certain conditions a central inter-sensory factor.

CHAPTER 111

STIMULUS AND TEST TONE VARIABLES IN TTS.

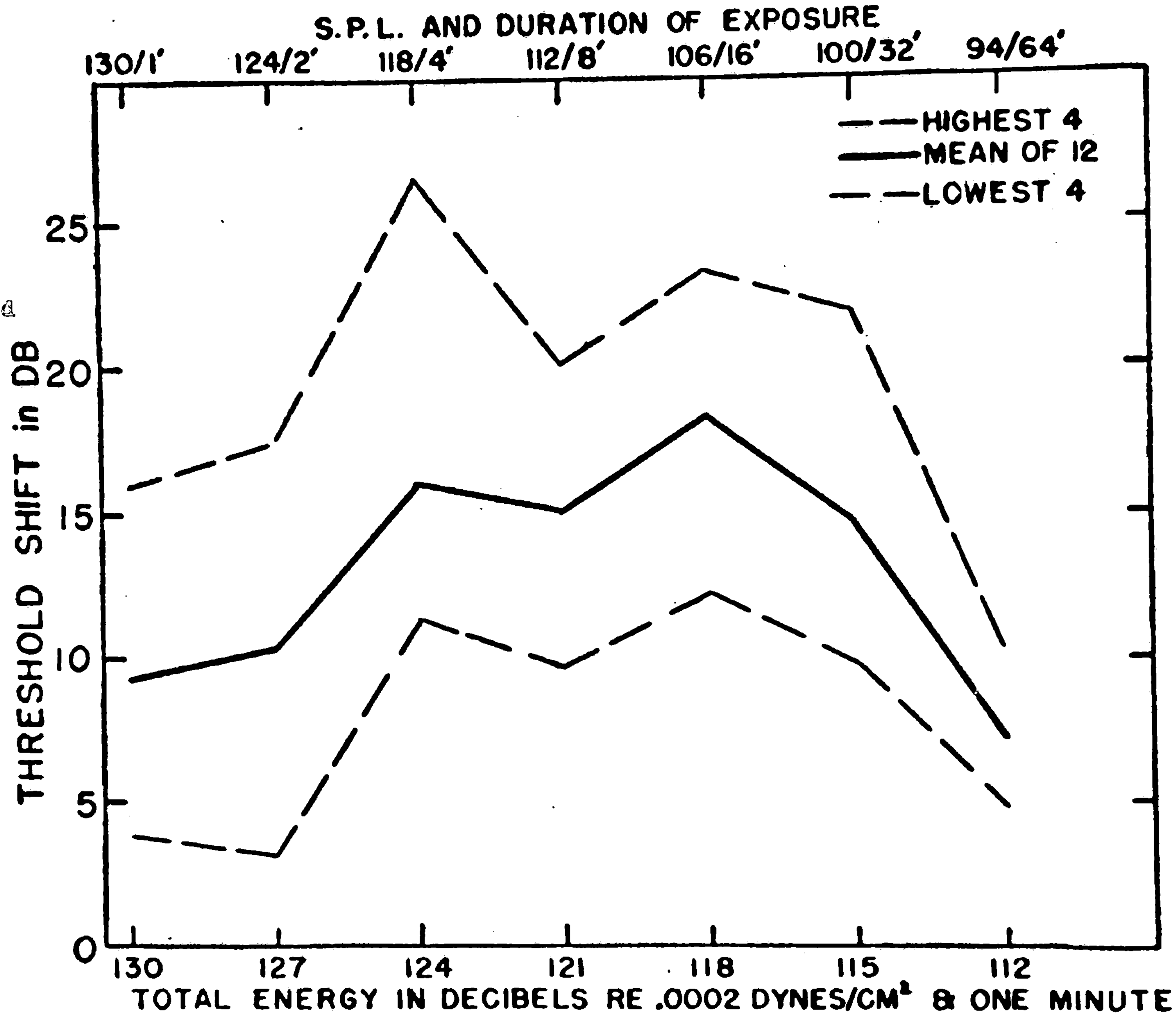
(a) Stimulus Duration : The results obtained in experiments studying the effects of stimulus duration on TTS are more conclusive than those obtained in experiments studying the other stimulus variables. Ewing and Littler (1935) noted that TTS increased as the duration of the stimulus was increased. Caussé and Chavasse (1942-43) found that with a stimulus tone of 1000 cps at stimulus intensities of 10-40 db., the amount of TTS increased linearly with the logarithm of the stimulus duration as the latter was increased from 10 to 40 seconds. Hood (1950) has extended the work of Caussé and Chavasse. He used a stimulus tone of 2048 cps at an intensity of 100 db. and found that as the duration was increased from 10 to 320 seconds the amount of TTS increased linearly with the logarithm of the stimulus duration. Ward, Glorig and Sklar (1959) and Ward, Glorig and Selters (1960) have also obtained a logarithmically linear increase in TTS with the stimulus duration as the effective duration of the stimulus is increased from 10 to 30 minutes or from 30 to 500 minutes respectively. In both of the latter studies the stimulus used was octave band noise.

However, it does not appear that Hood and Ward et al. are studying the same effect since Davis, Morgan, Hawkins, Galambos and Smith (1950) have claimed that as the stimulus duration is increased from 1 to 64 minutes the graph of TTS against stimulus duration changes from linearity to positive acceleration. Careful inspection of the results of Davis et al. reveals that the linearity at the lower durations is rather forced. The results could also represent two stages of a positively accelerating curve which, when transposed, would give a logarithmically linear increase in TTS with both long and short stimulus durations. The linear increases would of course have different slopes which would indicate that there are two TTS effects manifested. One seemingly associated with short stimulus durations and the other seemingly associated with fairly long stimulus durations.

One would expect that there exists some relationship between stimulus duration and stimulus intensity. For example "Rol has found bursts of a stimulus are less effective than a continuous stimulus" (see

PLATE II

Illustrates the results of Spieth and Trittipoe (1958b) in which they obtained a bow-shaped relation between TTS and different stimulus intensity/stimulus duration conditions.



Spieth and Trittipoe, 1958a). The United States Air Force assumes that intensity and duration have equal weightings in calculating noise exposure hazards. (See Ward et al., op. cit.). By analogy it has been suggested (see Spieth and Trittipoe, 1958a) that a similar condition applies in TTS. However, experimental results do not confirm this hypothesis. Spieth and Trittipoe (1958b) have analysed the results of Davis et al. (op. cit.) and found "that for two exposures to a tone, both having equal total energy, the exposure with the lower intensity and the longer duration nearly always produced the greater and more persistent TTS." Haris (1953) has reported similar results.

Spieth and Trittipoe (1958a) offered more evidence against the suggestion of equal weighting when they found that 1m/sec. bursts of noise had considerably less effect than equivalent continuous stimulation. They also less extensively tested burst of noise of 10m/sec. and 1 second duration. They concluded that these caused no more TTS than continuous stimulation and probably had a smaller effect. In a later study (Spieth and Trittipoe, 1958b) they found that 20 seconds after exposure,TTS was greater with increased stimulus intensities irrespective of the stimulus duration. When TTS was measured five minutes after exposure they obtained results (see plate 11) in which the relationships were typically bow - shaped. They suggest that at moderate intensities a 2 to 1 weighting of stimulus duration to stimulus intensity may be more appropriate. They also point out that as the intensity is increased this relationship must eventually become invalid.

Ward et al. (op. cit.) carried out further investigations on this phenomenon and concluded that the hypotheses of equal weighting and of 2 to 1 weighting both held under certain limited conditions. However, they also concluded that the relationship was much more complicated than suggested by either of these equations. Unfortunately neither Ward et al. nor any other workers studied stimulus intensities of less than the critical stimulus intensity of approximately 95 db. (see page 17). Consequently, it becomes impossible to say with any certainty whether the duality of results associated with variations in the stimulus duration would persist in the relationship. However, the hypotheses of equal weighting and of 2 to 1 weighting both seem to assume a logarithmic linear relationship between TTS and stimulus duration without the existence of any critical duration similar to the critical stimulus intensity. It will be shown later that this assumption cannot be made (see page 69). Similarly they would also seem to assume a logarithmic linear recovery from TTS. However, Ward (1960) has shown that if TTS is high, this relationship only applies in the initial stages of recovery.

We can conclude that the effect of stimulus duration on TTS reveals a dual effect. It appears that when the results of different experiments are interelated, the TTS increases linearly with the logarithm of the stimulus duration over a wide range of stimulus durations. However, it also seems fairly clear that this linear increase sub-divides itself into two parts. The relationship between stimulus duration and stimulus intensity is approximately 1 to 1 or 2 to 1 under certain limited conditions. However, the complete relationship is much more complicated and as yet it has not been related to the critical stimulus intensity or the critical stimulus duration.

(b) <u>Stimulus Intensity</u> : Ewing and Littler (1935) were the first writers to suggest that there might be a critical stimulus intensity associated with TTS effects. They did this indirectly when they suggested that there were two kinds of "fatigue" and that the threshold of feeling is not an adequate indicator of"overloading" of the ear. Hood (1950) points out that this idea is also suggested when the small amounts of TTS recorded by Ewing and Littler and obtained with stimulus intensities of up to 110 db. are compared with the much greater shifts recorded by Davis, Morgan, Hawkins, Galambos and Smith (1950) with stimulus intensities of up to 130 db.

Hood (op. cit.) was the first worker to effectively show the existence of a critical stimulus intensity. Using a stimulus frequency of 2048 cps, a stimulus duration of one minute and a latency of ten seconds he found that TTS increases only slightly as the stimulus intensity is raised from 60 to 90 db. However, he also observed that it increases rapidly as the stimulus intensity is raised from 95 to

110 db. The results of Davis et al. (op. cit.) also usually show that as the stimulus is increased from 110 to 130 db., further rapid increases in TTS occur. Jerger (1956) in his studies on diphasic recovery from TTS also noted that rapid increases in TTS occur with stimulus intensities exceeding 95 db.

Ward, Glorig, and Sklar (1958) using octave-band noise and a 4000 cps test tone, have suggested that the increases in TTS with stimulus intensities above the critical stimulus intensity are linear. Initially they suggested that the function was represented by the following equation :

$$TTS_2 = 1.06 \left[\sum_{i=1}^{n} R_i (S_i - 85)\right] \left[\log_{10} \frac{T}{1.7}\right]$$

where TTS_2 = TTS two minutes after cessation of the stimulus

R_i = ratio of time on to time off.[1]

S_i = Stimulus intensity (which must be greater than or equal to 85 db.).

T = Duration of stimulus

Later this equation was revised to :

$$TTS_2 = 0.61 [S_i - 70] [\log_{10} T + 0.33] - 9.5$$

where $R_i = 1$ and the symbols have the same meaning as in the first equation.[2] These equations of course only apply to the specific data collected by Ward et al.

It is difficult to judge from Hood's data whether this increase in TTS above 95 db. is linear since he only used stimulus intensities of 60, 70, 80, 90, 100 and 110 db. However, judging from the above points, they do not appear to be so. Hence, at first sight Hood's results and the results of Ward et al. appear to be contradictory. The discrepancy possibly reflects the existence of two TTS effects. Hood measured his TTS ten seconds after the cessation of the exposure tone, whereas Ward et al. measured their TTS over a two minute period

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1. Note; if stimulation is continuous R = 1.
2. Note; that Ward et al. actually used different symbols in the second equation, but these were equivalent.

after the cessation of the exposure tone. The former is definitely in the first phase of recovery from TTS and the latter is definitely in the second phase of recovery from TTS (see page 29).

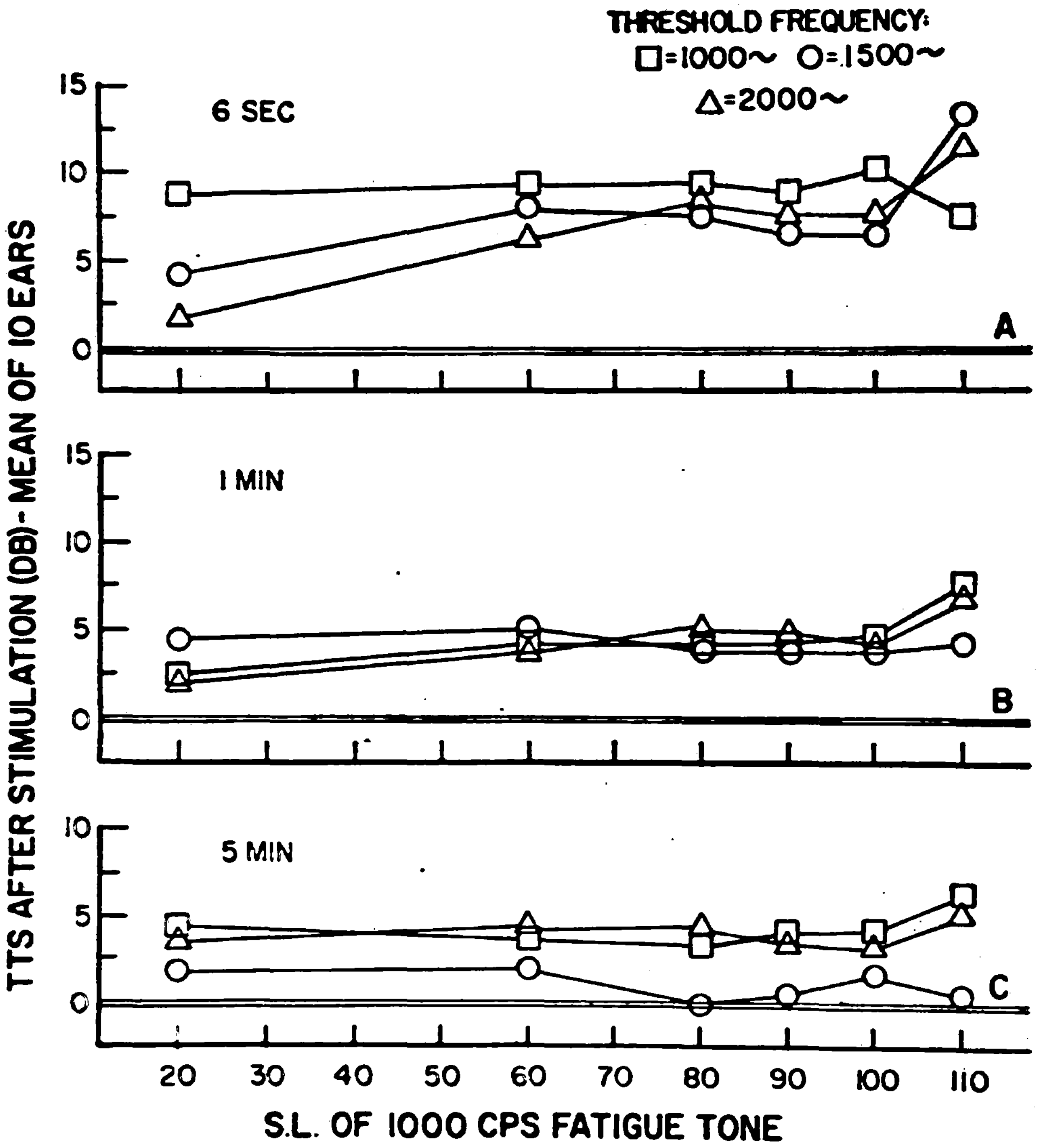
Further evidence for the existence of a critical TTS stimulus intensity has been provided by Epstein and Schubert (1957). They used not only the amount of TTS, but also the recovery time and the amount of recruitment present in an attempt to determine the critical TTS intensity of a thermal noise stimulus with a duration of 3 minutes. They used a 4000 cps test tone and found that at latencies of 5, 10, 20 and 60 seconds there is a sudden increase in TTS at 80 db. A composite expression utilizing TTS, recovery time and recruitment gave a similar increase at 80 db. Unfortunately, the latter result of Epstein and Schubert must be viewed with reserve, since they used the width of the excursions in Békésy tracing to measure the amount of recruitment present. The validity of this method has been questioned (see page 44).

There is some evidence that the existence of a critical stimulus intensity for TTS is not a universal phenomenon. Davis et al. (op. cit.) noted that for some subjects there was a reduction in the amount of TTS as the stimulus intensity was raised from 120 to 135 db. Trittipoe (1958a) also noted that although he obtained consistent increases in the mean TTS as a thermal noise stimulus was increased from 108 to 125 db., some of his subjects showed a consistently downward trend with increased stimulus intensities. In the latter case the intensity differences were tested and this downward trend was found to be statistically significant. We may conclude that this difference reflects a duality of TTS effects and that those subjects showing the downward trend are highly resistant to high intensity TTS.

Lawrence and Yantis (1957) have claimed that Hirsh and Bilger (1955) found "no significant differences in the amount of fatigue for the stimulus tone following levels of stimulation up to a sensation level of 100 db." In actual fact they obtained this result with only short duration exposure tones when <u>TTS was measured at the stimulus frequency</u>. Moreover, even when the test and stimulus frequencies were the same value Hirsh and Bilger found a large increase in TTS at a stimulus intensity of 90 db. and with a stimulus duration of four minutes. Their negative results with short stimulus durations may result from chance errors associated with the small amounts of TTS produced when the stimulus and test frequencies have the same value. The majority of the shifts they recorded under these conditions were less than 5 db. However, it seems more likely that TTS at a 1000 cps test frequency does not show any sudden increase with increased stimulus intensities. Careful study of the results of Miller (1958) reveals that TTS, after exposure to white noise, shows a sudden increase at approximately 95 db. stimulus intensity with test frequencies of 2000 - 8000 cps. With test frequencies of 500 and 1000 cps it shows no such sudden increase. Lawrence and Yantis (op. cit.) have also obtained negative results with a 1000 cps stimulus and Davis et al. (op. cit.) have shown that test frequencies of 2000 - 6000 cps are most affected by high intensity stimulation. Hirsh and Bilger categorically state that when TTS was measured at a test frequency a half octave above the stimulus frequency "above 90 db. the amount of .... THL increases sharply."[1]

Lawrence and Yantis (op. cit.) used TTS and overload (frequency distortion) to measure the effects of preceding stimulation on the responses of the ear. They used the Békésy technique to measure both the TTS and the overload. In the case of overload, the phenomenon of beats between aural harmonics and the test tone determined the width and mean point of fluctuation during the Békésy tracing. They found that although there was no increase in TTS, there was an increase in overload with increased intensities of stimulation. Lawrence and Yantis's results can be criticised because they measured TTS at a test frequency equal to the frequency of the stimulus tone. We have already seen in the case of Hirsh and Bilger's results that under these conditions TTS is very small and it is difficult to make an adequate assessment of any changes. Another criticism of Lawrence and Yantis's results is that although they

[1] THL (Temporary Hearing Loss) was the term used by Hirsh and Bilger, but it means TTS.



<u>PLATE III</u>

Illustrates the results of Lawrence and Yantis in which TTS <u>did</u> <u>increase</u> at approximately 100 db. with a test frequency above the stimulus frequency. The three separate graphs show TTS measured at the indicated latent times.

(Reproduced from Lawrence and Yantis, 1957) state that "post-stimulus fatigue .... showed little variation with stimulus intensity" their results were not completely negative. Plate 111 reproduces results obtained by Lawrence and Yantis in another experiment designed to ascertain a suitable intensity for the commencement of the overload experiments. In these they did measure TTS not only at equal test and stimulus frequencies but also at test frequencies a half an octave and one octave above the stimulus intensity. It can be seen from the plate that under the latter conditions, there are sudden increases in TTS at approximately 100 db. as the stimulus intensity is increased. However, in discussing their results they completely ignored this and concentrated upon the results obtained with equal stimulus and test frequencies.

Stimuli even at low intensities which normally produce very little observable TTS, may produce an increased susceptibility to TTS. This was suggested by studies of Trittipoe (1958 a and b) in which he stimulated subjects for 3 minutes with 118 db. noise after previous exposure to either 15 minutes silence or 15 minutes noise at a variety of intensities ranging from 48 to 88 db. These stimuli, according to Trittipoe, produced no observable TTS. He found that TTS was significantly affected by the previous noise exposure. However, there were wide individual differences. The result is dependent upon Trittipoe's statement that the noise at the 48-88 db. level produces no observable TTS. Unfortunately, he did not use a "commercial" noise so we cannot directly judge for his particular conditions. However, there is great amount of information available to show that exposures at this level do produce TTS if the latencies are sufficiently small. (See for example Caussé and Chavasse, op. cit. and Hood, op. cit.)

The incorrectness of Trittipoe's assumption is confirmed by more recent experiments of Ward (1961). He used stimulus intensities of 60 and 70 db. to produce latent effects. However, he took precautions to prevent the <u>observable</u> TTS effects produced by the pre-exposure stimuli from affecting subsequent measures of TTS. Under these conditions he found "that latent effects are at best neglible." It seems unlikely that exposures at stimulus intensities less than the critical stimulus intensity (approximately 95 db.) would produce true residual effects for stimulus intensities greater than the critical stimulus intensities. Intensities above and below the critical intensity seem to be associated with different TTS phenomenon.

In summary it would appear fairly well established that there exists a critical stimulus intensity of approximately 95 db. Below this the differences in TTS with stimulus intensity are slight; whereas above this, TTS increases linearly with stimulus intensity. The effects observable above the critical stimulus intensity do not reveal themselves at a 1000 cps test frequency. They are probably associated with the two phases of recovery from TTS. The high intensity effects do not appear to be affected by prior stimulation at intensities less than the critical intensity.

(c) Stimulus Frequency. The earlier work of Ewing and Littler (1935) and Rawdon-Smith (1934 and 1936) indicated that stimulus frequencies above 1000 cps produced more TTS than stimulus frequencies of less than 1000 cps. Békésy (1929) even reached the erroneous conclusion that frequencies of less than 1000 cps did not produce any TTS. However, Békésy's result probably arose from the lack of a suitable technique to obtain a rapid determination of the post-exposure threshold. Hence by the time he had measured the post-exposure threshold, the TTS effects had been dissipated.

The first comprehensive study on the role of the stimulus frequency in producing TTS was carried out by Davis, Hawkins, Morgan, Galambos and Smith (1950). Using stimulus intensities of 120 to 140 db., these workers found that a 500 cps stimulus tone was least effective in producing TTS, that 1000 and 2000 cps stimulus tones were equally effective in producing TTS and that a 4000 cps stimulus tone was most effective in producing TTS. However, a careful inspection of their results reveals that for some individual subjects, a 2000 cps stimulus tone was slightly more effective than a 1000 cps stimulus tone.

These results did not agree with results published earlier by Caussé and Chavasse (1942-43). Using a test frequency equal to the stimulus frequency, they found that fatigue was maximal at a stimulus frequency of 3000 cps with stimulus intensities of 30-40 db. However, since they did not use stimulus/test frequencies of 2000 and 4000 cps, it may be that the

3000 cps peak is simply an artifact. However, it seems unlikely that we can explain the discrepancy in this way, since Hood (1950) obtained maximal TTS at 900, 1800 and 2700 cps stimulus frequencies. A more important difference between the work of Caussé and Chavasse and Davis et al. is that they used very different stimulus intensities. It has been established (see pages 17 to 21) that there is a change in the nature of TTS at the critical stimulus intensity of approximately 95 db. Since Caussé and Chavasse used stimulus intensities of 30 to 40 db. and Davis et al. used stimulus intensities of 120 to 140 db., they were obviously measuring two entirely different effects.

If Caussé and Chavasse had tested more intermediate frequencies they might well have obtained similar results to those of Hood. It was stated above that he found that TTS was maximal at stimulus frequencies of 900, 1800 and 2700 cps. His results also show that TTS at these peak maxima increases as the stimulus frequency increases. Thus TTS at 900 cps is less than TTS at 1800 or 2700 cps, although it is greater than at all other stimulus frequencies. Similarly TTS at 1800 cps is less than TTS at 2700 cps. He makes no reference to a maximum at 4000 cps and again this is contrary to the results of Davis et al. However, two of the individual results that he shows do have a further maximum at about 4000 cps. In his mean graphs no frequencies above 3600 cps are shown. Hence it is impossible to judge whether such a maximum was present. Hood relates his work to the work of Derbyshire and Davis (1935) on equilibration and the volleying of the auditory nerve. Thus at approximately 1000, 2000 and 3000 cps, the auditory nerve fibres are firing at their maximal rate and consequently the time between impulses in individual fibres is only fractionally greater than the absolute refractory period of the fibres. He hypothesised that TTS would be maximal at these frequencies since the nerve has virtually no time to recovery between successive impulses.

Despite the excellent quality of Hood's work it can be criticised on three points :

(i) He used only one stimulus intensity to study the effect.

(ii) He used a stimulus intensity of 100 db. which is very close to the critical stimulus intensity.

(iii) He measured TTS at a latency of one minute which, as we shall see later, is a transition point in the two stages of recovery from TTS (see page 17).

The criticisms do not invalidate Hood's work but they do mean that further experimentation is necessary before the results can be accepted as being generally applicable. The author's own work has shown that there are limitations on the conditions under which Hood's results apply.

The greater influence of 4000 cps in producing TTS at moderately high intensities is confirmed by results published by Ward, Glorig and Sklar (1959a). They found that when octave band noise was used as a stimulus, maximal TTS was produced by the band 2400 - 4800 cps at stimulus intensities of 90 to 105 db. Thompson and Gales (1961) have shown that TTS at 4 kc is independent of the bandwidth of the stimulus. They used noise stimuli at a sound pressure level of 110 db. and with bandwidths of up to one octave. Hence it seems safe to conclude that the results of Ward et al. indicate the greater effectiveness of 4000 cps pure tone in producing TTS. Hirsh and Ward's work (1952) on diphasic recovery from TTS is also indicative of the twofold nature of the stimulus frequency variable. They state that "after acoustic stimulation by sounds containing at least some frequencies below 4000 cps the recovery of the auditory threshold .... is represented by a diphasic curve."

In conclusion it would appear that depending upon the severity of the exposure and particularly upon the stimulus intensity, TTS is maximal at 1000, 2000 and 3000 cps or at 4000 cps. With intensities of less than approximately 85 to 100 db. the former condition seems to prevail. It is difficult to predict what happens at higher intensities, since an intensive study of these has not been reported. Davis et al. (op. cit.) used only frequencies of 500, 1000, 2000 and 4000 cps and the bands of noise of Ward et al. (op. cit.) were too wide to determine any intermediate frequency effects. A 4000 cps stimulus is the most effective of those extensively tested, but whether the maxima at 1000, 2000 and 3000 cps still persist, is uncertain.

(d) Test Tone Relationships in TTS. Once again Ewing and Littler's (1935) work was indicative of later results. They suggested that maximal TTS occured at frequencies above the stimulus tone and that it spread over about two octaves. Perlman (1942) made a similar suggestion but neither he nor Ewing and Littler had anything more specific to say on the problem.

The first detailed results came from Davis, Hawkins, Morgan, Galambos and Smith (1950) who found that "the greatest loss of sensitivity occurs at a frequency about half an octave above the exposure tone." The results of Davis et al. also showed that a stimulus tone of duration one or two minutes produced a spread of TTS over one or two octaves. This confirmed the suggestion of Ewing and Littler and of Perlman. However, Davis et al. also noted that with longer stimulus durations, i.e. 32 and 64 minutes, the range of test frequencies showing observable TTS exceeded two octaves.

Kylin (1961) using filtered white noise stimuli has extended the work of Davis et al. He found the band of test frequencies affected increases in width as the intensity of stimulation is increased. However, contrary to the results of Davis et al., he claimed that whatever the stimulus conditions the band of frequencies affected never covered a range of more than two octaves. This discrepancy does not seem to be associated with the use of noise instead pure tone stimuli, since one would expect a greater band of frequencies to be affected by noise than by pure tones. The discrepancy is more likely to be a function of stimulus intensity, since Kylin only used stimulus intensities of up to 115 db. whereas Davis et al. used stimulus intensities of 120 to 140 db.

Kylin's results certainly do not hold when unfiltered noise is used as a stimulus. Postman and Egan (1949) used unfiltered white noise as a stimulus tone and found that 30 seconds after exposure, a range of frequencies from 250 to 8000 cps were effected. Since 8000 cps was the highest frequency tested the range of frequencies affected may have been even greater. However, the range of frequencies most seriously affected is from 2000 to 8000 cps and this equates with the 2 octaves suggested by Kylin. Davis et al. (op. cit.) have suggested that the test frequencies most seriously affected are from 2000 to 6000 cps and this result has been confirmed by Ruedi and Furrer (1946 and 1947)

It is possible in summarizing these discrepancies to make two suggestions to explain the differences. These are that :

(i) Kylin's results are not general and that they are an artifact produced by the use of limited stimulus conditions.

(ii) Kylin's filtered white noise equates more to pure tones than white noise and that his results hold for pure tone but not for noise stimuli.

The latter suggestion is hardly tenable since Davis used noise as well as pure tones. Consequently it would appear that the former suggestion is more likely to be correct.

The results of Davis et al. and Kylin are contrary to those of Caussé and Chavasse (1942-43) who found that with low intensity stimulus tones there is a symmetrical spread of fatigue about a test frequency equal to the stimulus frequency. Earlier results by Békésy (1929) and Rawdon-Smith (1934 and 1936) had also indicated that maximal TTS occurs at the stimulus frequency. Hirsh and Bilger (1955) have suggested that for low intensity levels of the stimulation, a test frequency equal to that of the stimulus tone is most adversly affected. They noted that as the stimulus intensity was increased, TTS spread to the higher intensities until maximal TTS occured at a test frequency a half octave above the stimulus frequency. Lawrence and Yantis (1957) confirmed these results but also noted that although TTS was maximum at a test frequency of 1500 cps, after exposure to a 1000 cps tone, recovery from TTS was slower at a test frequency of 2000 cps than at a test frequency of 1500 cps.

Hood (1950) has resolved the conflict in a series of experiments in which he observed the distribution of TTS with test frequency at stimulus intensities of 60, 80 and 100 db. At 60 db. he obtained the symmetrical TTS spectrum obtained by Caussé and Chavasse. At 80 db. the higher frequencies shows TTS effects and at 100 db., the higher frequencies show even greater effects and the maximal TTS occurs at a frequency half an octave above the stimulus frequency.

Again we must conclude that TTS exhibits a dual phenomenon. At stimulus intensities less than the critical stimulus intensity, the TTS distributes itself symmetrically about the stimulus frequency. At intensities above the critical intensity, the TTS distributes itself symmetrically around a frequency a half an octave above the stimulus frequency. The interrelationships of this effect with stimulus duration have not been investigated.

CHAPTER 1V

RECOVERY FROM TEMPORARY THRESHOLD SHIFT.

The main experimental parameter in recovery from TTS is the latency. The other experimental parameters will of course affect the rate or type of recovery; but recovery concerns itself primarily with the amount of TTS specifically observable after given latent times.

During the past decade, there has been a great deal of controversy over the temporal course of recovery from TTS. Some workers (see Hirsh and Ward, 1952, Hirsh and Bilger, 1955 and Jerger, 1956) have suggested that recovery from TTS is diphasic. However, other workers (see Hood, 1950, Harris, 1953 and Epstein and Schubert, 1957) have disagreed with this suggestion and state that recovery is simply monophasic. Typical "diphasic recovery" curves are shown in plate 1V which is reproduced from Hirsh and Ward, (op. cit., page 133). Typical "monophasic recovery" curves are shown in plate V which is reproduced from Hirsh and Ward (op. cit., page 135).

Hirsh and Ward carried out two separate experiments into recovery from TTS. In the first study, clicks varying in intensity in 3 db. steps were used to measure the pre-exposure and the post-exposure thresholds. Using stimulus tones of 125 to 4000 cps and stimulus intensities of 120 db., they found that recovery was diphasic. Inspection of plate 1V reveals that the two phases in the recovery are :

(i) An initial rapid recovery of the threshold to normality, near-normality or super normality which is complete after about one minute.

(ii) Following the initial recovery a further gradual elevation of the threshold which lasts for a further minute or thereabouts. This is followed by a further gradual recovery of the threshold to normality.

They introduced the term "bounce". This referred to the difference between the lowest threshold value reached in the initial phase of recovery and the highest threshold value reached in the second phase of recovery. They found that bounce was maximal at a stimulus frequency of 500 cps. Further experiments with a 500 cps stimulus tone at stimulus

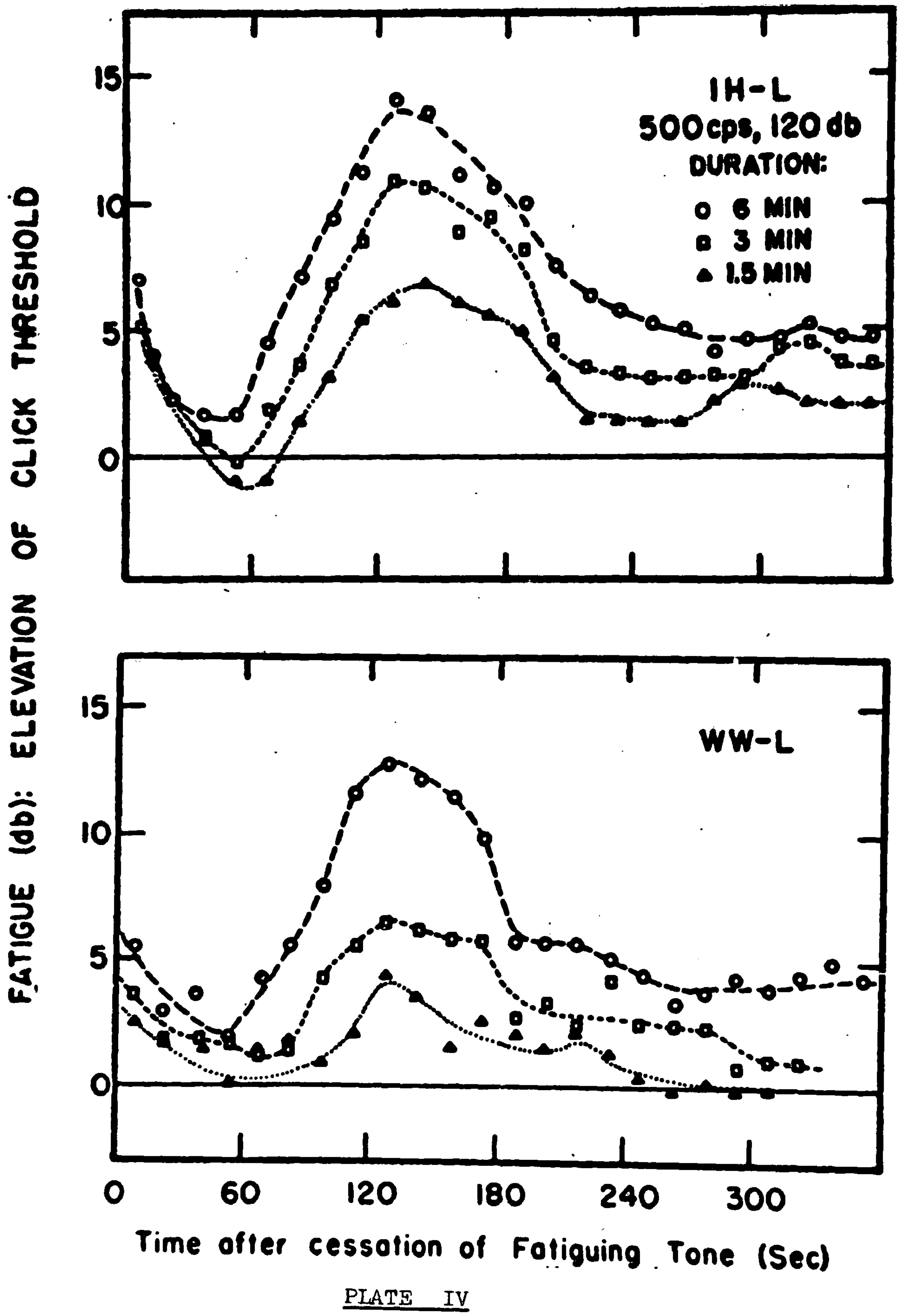


PLATE IV

Illustrates diphasic recovery from Temporary Threshold Shift. (Reproduced from Hirsh and Ward, 1952).

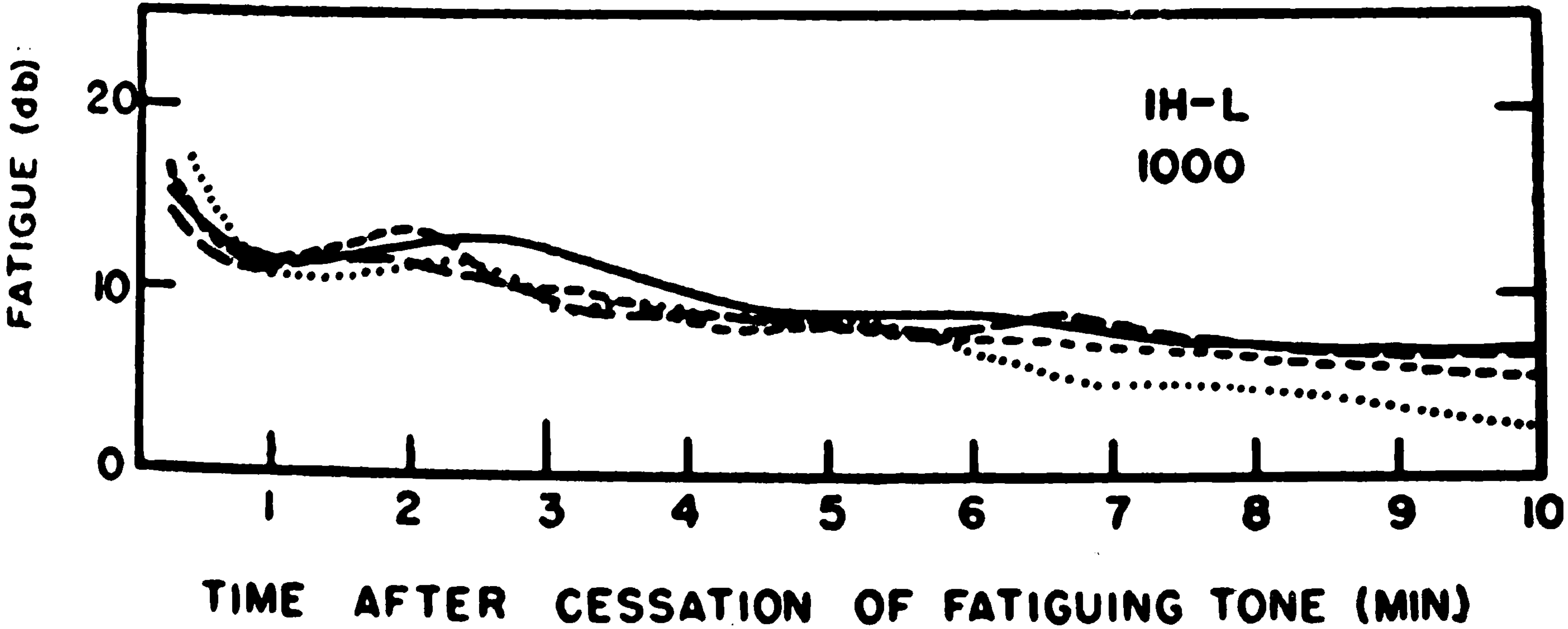


Plate V.

Illustrates monophasic recovery from Temporary Threshold Shift. (Reproduced from Hirsh and Ward, 1952).

intensities of 100, 110 and 120 db. and with stimulus durations of 1.5, 3 and 6 minutes, revealed that the amount of bounce increased as the severity of the stimulus tone increased. This finding was later confirmed by Hirsh and Burn in an unpublished study (see Hirsh and Bilger, op. cit.). Similar results were obtained when narrow bands of noise were used as stimuli instead of pure tones.

In a second series of experiments Hirsh and Ward used the Békésy technique to measure the pre-exposure and the post-exposure thresholds. They used white noise and pure tone stimuli and pure tones of 350 to 8000 cps and ten bands of noise covering the range 160 to 6600 cps in 250 mel bands as test sounds. The results showed that the amount of bounce was greatest for test frequencies covering the range 1000 to 5000 cps. Within this range it was found to be maximal at 4000 cps. In the final experiment the effects of increased oxygen intake on recovery were found to be slight and there was little evidence of any facilitatory effects.

Work by Lierle and Reger (1954) indicated that the phenomenon is related to the stimulus intensity. These workers did not study the temporal course of recovery directly. However using a pure tone stimulus of 1000 cps at intensities of 20 and 80 db. they found that with a stimulus duration of one minute, the threshold elevation at 20 db. was 0.28 db. higher than the threshold elevation at 80 db. When the stimulus duration was increased to 30 minutes the TTS was found to be greater at an 80 db. stimulus intensity.

Further information on the role of stimulus intensity in producing diphasic or monophasic recovery was provided by Hughes (1954) and Hirsh and Bilger (op. cit.). Hughes used a stimulus frequency of 500 cps, stimulus durations of one, two or three minutes and a variety of stimulus intensities. He used the Békésy technique for measuring thresholds at a variety of test frequencies and recorded post-exposure thresholds for six to seven minutes after the cessation of the stimulus. He rather confusingly defines "sensitization" as the amount of bounce. Hirsh and Ward (op. cit.) previously used the term to refer to whether or not in the first phase of recovery the threshold decreased below the value of the pre-exposure threshold. Since sensitization means an increase in sensitivity, it is felt that Hirsh and Ward's use of the term is more logical and it will be used in this context throughout this thesis. Hughes claimed that whenever diphasic recovery was present, so was sensitization and he justified his use of the term on these grounds. This suggestion is not borne out by later work of Hughes and Rosenblith (1957). They used clicks to measure the first neural response of the ear and then used this to study TTS effects in cats. They found that in certain cases, depending upon the stimulus conditions, their cats were consistant in showing sensitization but not diphasic recovery.

Hughes found that no bounce occured with stimulus intensities of less than 60 db. and that when bounce occured it was maximal at a stimulus duration of three minutes. The former result was partially confirmed by Palva (1958) who found that only 10% of recovery curves showed diphasic recovery with a stimulus intensity of 30 db. Hughes also found that bounce was maximal at a test frequency of 500 cps,i.e. at a frequency equal to the stimulus frequency. This result does not directly contradict the results of Hirsh and Ward (op. cit.) who found bounce was maximal at 4000 cps since Hughes only used test frequencies of 100 to 1000 cps whereas Hirsh and Ward tested frequencies up to 8000 cps. It may be that there are two maxima, one at 4000 cps and one at the stimulus frequency. Hughes finally states that there are usually two intermediate peaks in the initial recovery phase. However, the author feels that these results from variations in threshold produced by the Bekesy method (see page 45), particularly since the intermediate peaks reflect very small changes in the threshold.

Hirsh and Bilger (1955) confirmed the relationship between recovery and stimulus intensity. Using a 1000 cps stimulus tone at intensities of 20 to 100 db. and with stimulus durations of 5 seconds to four minutes, they found that whether recovery was measured at 1000 or 1400 cps, it was diphasic except with stimulus durations of 15 seconds. In the latter case recovery was monophasic at all intensities. They also found that the second phase of recovery was prolonged as the stimulus duration was increased. They did not confirm the existence of further peaks in the first phase of recovery.

Contrary to the above results Hood (op.cit.), Harris (op.cit.) and Epstein and Schubert (op.cit.) claim that recovery from TTS is monophasic under all stimulus conditions. Hood used the Bekesy technique to study a range of stimulus conditions in his comprehensive study of "post-stimulatory fatigue". None of his individual or mean results show any evidence for diphasic recovery and he makes no reference to it in his paper. However, Hood's results have been constructively criticised by Hirsh and Ward (op.cit.). The latter point out that the construction of Hood's apparatus allowed the subjects to position the subject-controlled attenuator by reference to its preceeding positions. They state, concerning the absence of diphasic recovery, that "this grounding produced by spatial organization might have precluded the appearance of this temporal change."

Harris used stimulus intensities of 120 to 140 db. and failed to find any evidence for diphasic recovery using a Bekesy technique for the threshold measurements. He maintained that the results of Hirsh and Ward (op.cit.) were an artifact produced by tinnitus resulting from over stimulation of the ear. It is difficult to reconcile this statement with the fact that he used more severe exposure than Hirsh and Ward. It would be expected that this artifact would be even more evident in his results. Harris's results were not easily explained until Jerger (op.cit.) showed that diphasic recovery is limited by an upper as well as a lower stimulus intensity. Using a 3000 cps stimulus tone with a stimulus duration of two minutes, he found that at a 95 db. stimulus intensity there was a sudden increase in the amount of bounce. As the stimulus intensity was further increased, his results showed that there was a gradual decrease in the amount of bounce until at 110 db. it completely disappeared. Spieth and Trittipoe (1958a) have to some extent confirmed Jerger's results. They show for other reasons curves of recovery from TTS obtained under a variety of stimulus conditions, using intensities ranging from 94 to 130 db. in 6 db. steps. Careful inspection of these curves reveals that diphasic recovery only occurs with stimulus intensities of less than 106 db. Hence, it would appear that the negative results of Harris are associated with the fact that he used stimulus intensities greater than those at which recovery from TTS is diphasic.

The negative results of Epstein and Schubert would also seem to result from the use of an inappropriate stimulus. In experiments which specifically set out amongst other things to investigate this problem, they used a stimulus tone of 4000 cps at intensities ranging from 70 to 10 db. with a stimulus duration of 3 minutes. Recovery was observed at test frequencies ranging from 3000 to 8000 cps and they obtained no recovery curves of the diphasic type. However, Hirsh and Ward (op. cit.) stated that recovery with a 4000 cps stimulus was monophasic. It is difficult to understand why they chose a 4000 cps stimulus in view of the earlier results of Hirsh and Ward and one would not expect their results to show diphasic recovery.

All the papers claiming diphasic recovery from TTS noted that there were widespread individual differences in the manifestation of the phenomenon. Lightfoot (1955) undertook an extensive study of these inter-subject and intra-subject difference. He tested 24 subjects twice with four stimulus/test conditions and obtained 192 recordings of recovery from TTS. He found that 48% of these were judged to be monophasic and 52% were judged to be diphasic. He subdivided the diphasic results by classifying them into three different types. These were :

(i) Those showing only one bounce.

(ii) Those showing two or more bounces.

(iii) Those showing a bounce higher than the initial elevation in threshold.

He found that 54 results showed recovery of the first type, 30 results showed recovery of the second type, 7 cases showed recovery of the third type and in 9 cases the judges could not agree on the classification. With regard to intra-subject variability, he found that 68 out of 96 pairs of tracings involving the same stimulus/test conditions were consistent, 24 out of 48 sets of four tracings involving the same stimulus conditions were consistent, 13 out of 48 sets of four tracings involving the same test conditions were consistent and 1 out of 24 sets of 8 tracings involving all conditions was consistent. Only one subject was completely consistent in showing diphasic recovery in all of the experimental sessions.

However, the impression gained from this study is that the widespread individual variations in recovery are as much a quastion of experimental technique as of real individual variability. Judgements are notoriously unreliable and the initial figures of 48% monophasic and 52% diphasic seem to be "statistically" suspicious. Another factor to be born in mind is that Lightfoot used the Békésy technique for measuring the threshold. We have already referred to the lack of knowledge of what this technique actually measures (see page 5). The above suggestion is supported by the work of Hughes and Rosenblith (op. cit.) who found with cats that the recovery of the neural response from "adaptation" (TTS) consistently showed diphasic recovery or monophasic recovery under the appropriate stimulus conditions. Furthermore, Lightfoot's results are not confirmed by Thompson and Gales (1961) who found that under the appropriate stimulus conditions, "if an ear's mean curve shows "bounce" the individual curve for each stimulus type shows "bounce" also."

Recovery from TTS exhibits the typical dual nature of the phenomenon. The differences between monophasic and diphasic recovery seems to be a facet of the stimulus conditions. Low or extremely high intensity stimuli give a monophasic recovery whereas stimuli of an intermediate intensity give diphasic recovery. Stimuli of less than 4000 cps produce monophasic recovery, whereas stimuli of more than 4000 cps do not. The effect manifests itself most plainly at a test frequency of 4000 cps.

CHAPTER V.

MECHANISMS OF TTS.

Davis, Morgan, Hawkins, Galambos and Smith (1950) have suggested that TTS effects are related to temporary damage to the organ of Corti. Hood (1950) relates some of his findings to equilibration and some to place and frequency theories of the action of the cochlea. However, the first really systematic attempt to formulate a theory regarding the mechnnism of TTS came from Rosenblith (1950) in 1950. He noted that TTS and masking are similar in that both produce :

(i) "shifts in threshold."

(ii) "Changes in loudness."

(iii) "Changes in pitch."

(iv) "Effects upon localization."

(v) A symmetrical spread of the effect with low intensity stimulation, whereas high intensity stimulation produces an asymmetrical spread of the effect.

Experiments were reported in which changes in potential were recorded from the round window, the cochlear nucleus and the auditory cortex. The changes were associated with both masking and TTS stimuli and were recorded with human and animal subjects. Rosenblith concluded that, "although it is clear that the two effects cannot be unrelated unless we assume some strange discontinuities in the behaviour of the auditory system, it would seem to be going unnecessarily far to identify even the short-term after effects of an exposure stimulus as <u>residual</u> <u>masking</u>."

Rosenblith's suggestion that TTS is not entirely, if at all, explicable in terms of residual masking is supported by later experiments of van Dishoek (1953). These experiments directly compared TTS and masking effects for a 1000 cps stimulus. The distribution of these results over given test tones were similar. However, the amount of TTS was much greater than the amount of threshold elevation produced by masking. Miller (1958) has approached the problem in another way and measured TTS for critical band stimulus tones producing equal masking effects. On a residual masking theory of TTS one would expect that such stimuli would produce equal TTS effects. However, Miller found that this was not the case. A careful control experiment showed that frequency differences within critical bands could not accoun for this phenomenon.

The relationship between masking and recruitment suggests that the masking phenomenon is associated with the organ of Corti (see Garner, 1947). Despite the dissimilarities between masking and TTS, this does suggest that TTS may be an effect associated with the organ of Corti. Hood (op.cit.) implicitly assumes this when he discusses the theoretical importance of his results in terms of place and frequency theories of hearing. Huizing (1949) offered further evidence for this suggestion when he reported that subjects suffering from recruitment show a greater than normal susceptibility to TTS. Jerger (1955) has confirmed the importance of the inner ear in mediating TTS effects by studying the critical duration of a test tone. Miskolozy - Fodor (1953) has shown that the critical duration of a test tone stimulus is decreased in certain types of perceptive deafness. Below this critical duration the threshold alters as the test tone duration is decreased. Jerger measured thresholds at 4000 cps after stimulation by thermal noise and found that the critical duration was decreased in a similar manner to Miskolozy-Fodor's results. Since perceptive deafness is an inner ear phenomenon, we can assume that Jerger's results localize TTS in the inner ear.

Organ of Corti localization has been confirmed by Hallpike and Hood (1951). These workers used a binaural balance technique to measure the effect of TTS on the loudness of pure tones. They compared the development of changes in loudness as the stimulus duration was increased with sensory adaptation as it occurs in the stretch receptors of the muscle (see Mathews, 1939). They found a very close agreement between the two sets of results. In further experiments they directly compared TTS effects and recruitment and found them to show similar loudness - duration relationships. Hence they concluded that TTS is associated with sub-normal functioning of the organ of Corti. More direct evidence of the role of the organ of Corti of TTS effects is to be found in studies utilizing direct recording of the cochlear microphonic. Unfortunately, the only direct study of this nature is by Hughes and Rosenblith (1957).

These workers have shown that recovery of the cochlear microphonic exhibits many similarities to recovery from TTS.

Gardner (1947) has suggested a possible theory explaining the role of the cochlea in producing TTS. He suggests that TTS is mediated by means of "fatigue patterns" developing on the basilar membrane and/or the organ of Corti. He suggests that upon the termination of the stimulus tone, the fatigue pattern remains but gradually decreases in spread as the latent time increases. An applied test tone will be responded or not responded to, depending upon its own deformation of the membrane and the relationship of its own pattern to the fatigue pattern.

Koide, Yoshida, Konno, Nakano, Yoshikawa, Nagaba and Morimoto (1960) followed up the work of Wever, Lawrence, Hemphill and Straut (1949) and Gulick (1958) on the production of temporary and permanent increases in the threshold of the cochlear microphonic by oxygen deprivation. The validity of equating temporary and permanent losses is supported by the work of Gravendeel and Plomp (1959 and 1961) who in case of permanent losses induced by continuous noise found that "the permanent dip arises from the temporary dip by incomplete but symmetrical recovery." In the case of losses induced by intermittent noise they suggest that probably "the permanent dip arises from the temporary dip by incomplete asymmetrical recovery." However, the slight uncertainty of the latter statement is irrelevent since Koide et al. used continuous noises. They found that "sound stimulation and oxygen deprivation have similar effects", that is "decreasing the oxygen tension in the inner ear or altering the conditions of the inner ear blood vessels." After studying these changes and relating them to histological findings, they formulated a "physico-chemical" theory of the onset of acoustic trauma. It was also suggested that the same theory could be used to explain TTS effects. The theory suggests that the metabolic activity of the inner ear is affected at progressive levels. These levels depend on the amount of oxygen tension resulting from sound, but not from shock waves. Further study indicated that these changes were associated with "morphological changes of the mitochondrial structure of the apex" and suggested that oxygen tension was at least a "subordinate factor" in producing this effect. This theory seems to be important in providing a basic account of how TTS occurs at a cellular level; but unfortunately it throws little light on the frequency, intensity and duration relationships of TTS. These would seem to be associated with higher levels of functioning, such as the mode of deformation of the basilar membrane. However, it may be that the work of Koide et al. will lead to a bio-chemical theory of TTS in terms of circulatory changes in the ear.

The dual nature of TTS does not appear to be borne out by the experiments relating to its mechanisms. These experiments have usually utilized severe stimulus conditions and very few of them have utilized a stimulus intensity of less than 95 db. Consequently the discrepancy may partly result from the lack of an adequate study of all of the variables. However Rosenblith,(op. cit.), Hood (op. cit.) Hallpike and Hood (op. cit.) and Hughes and Rosenblith (op. cit.) did use less severe conditions and we should expect some indication of a dual phenomenon from their work. The only experiments indicative of this are those of Hughes and Rosenblith who found a two phase recovery in the *cochlear microphonic.* This finding reveals why the dual nature of TTS does not reveal itself in experiments on its mechanisms. These experiments have tended to treat the organ of Corti as a gross structure. If *both effects are associated with different aspects of the functioning of the organ of Corti*, then stimuli producing either effect will produce a gross cortical localization.

This suggestion is supported by Hood (1956). Hood suggests that the "inflexion" in the curve of TTS against stimulus intensity at 85-100 db. "suggests a dividing line between two different kinds of end-organ change : those that are physiological and reversible and those that are pathological and irreversible." Similarly Hirsh and Bilger (1955) have suggested that the two phases of recovery from TTS may possibly be explained in terms of the chemical excitability of receptor cells and the excitability of nerve fibres. They do not localize these effects but it is quite probable that both aspects of such a process could be localized in the organ of Corti.

We can conclude from work on the mechanisms of TTS that the effect is localized in the organ of Corti. However, TTS is not residual masking. It may be mediated by "fatigue patterns" remaining after the cessation of stimulation. These experiments do not reveal a dual TTS effect, but this is probably because of the tendency to treat the organ of Corti as a unitary whole. Diphasic recovery reveals itself in the cochlear microphonic. It is possible that the dual TTS effects are associated with physiological or pathological changes respectively.

CHAPTER VI

THE BÉKÉSY METHOD.

The Békésy method of threshold measurement was introduced by Békésy (1947), although Oldfield (1949 and 1955) claims to have invented it independently. It was novel in that it took away to some extent the experimenter's control of the independent variables of test intensity and test duration and placed these variables under the control of the subject. The method allows the subject to increase or decrease the intensity of a sound by pressing or releasing a push button which controls the drive mechanism of an automatic recording attenuator. Thus he oscillates between just hearing and just not hearing a tone and consequently he varies the intensity of the tone around his threshold. The most important advantage of the method is the speed with which thresholds can be measured. The method can also incorporate an automatic frequency control. Consequently thresholds over the whole of the audible frequency range can be measured and not just thresholds at the conventional audiometric test frequencies (125 to 8000 cps in half octave intervals).

Several papers have been subsequently published on the effects of physical variables, for example varying attenuation rates and the use of pulsed or continuous tones, on threshold measurements recorded using the Bekesy technique. These will be discussed later. Unfortunately, there have been no studies specifically designed to investigate the physiological or psychological processes which underlie the method. Because of this lack of information many studies utilizing the method must be viewed with reserve until more information is available. Epstein (1960) states that "there is no doubt that its potential as . . . . . . a diagnostic tool has yet to be fully explored."

Experiments studying the effects of physical variables on the threshold recordings have tended to concentrate on changes in the size of the excursions that the subject makes between responding, i.e. hearing the tone, and not responding, i.e. not hearing the tone. Békésy (op. cit.) indicates that excursions of about 5 db. can be considered to be normal. Lunborg (1952) and Reger (1952) using the same attenuation rates as Békésy have respectively reported that excursions of 6-9 db. are normal. Lunborg also suggests that the extreme limits of normality lie between 5 and 20 db.

Epstein (op, cit.) has shown that the size of the excursions also depends upon the rate of attenuation. He found that as the attenuation rate increased, the size of the excursions also increased. He states that "we measured ranges from 4-9 db., 5-17 db., 8-15 db. and 10-30 db. for attenuation rates of 1, 2, 3 and 6 db." Corso (1955) obtained similar results to Epstein's under more limited conditions, i.e. attenuation rates of 0.5, 1.0 and 2.0 db. / second. Since wider excursions are more prone to response errors, Corso suggests that an attenuation rate of 0.5 db. / second is optimum. However, as Epstein (op. cit.) points out, it is possible that the slower attenuation rates produce more boredom. This is to some extent confirmed by the results of Epstein (op. cit.) and Harbold and O'Connor (undated U.S. Navy publication). These workers showed that faster attenuation rates produce a lower mean threshold value. Corso (op. cit.) originally disagreed with this suggestion and found that neither the attenuation rate nor the period of testing affected the mean threshold value. In a later paper (Corso, 1956) he revised his findings and obtained similar results to Epstein's. A priori the phenomenon of response time would seem to be an important consideration in deciding an optimum attenuation rate. This is ignored by Epstein and Harbold and O'Connor. However, it would appear that the faster the attenuation rate the greater the backlash, i.e. the more the subject runs over the point at which he actually responds or does not respond to the tone. The response time will be much greater than the simple reaction time to sounds, since the subject has not only to react, but also he has to decide whether or not he hears the tone. If we assume for illustration that the response time is one second, then at an attenuation rate of 1 db. / second the width of the excursion will only increase by 2 db. because of this factor. However, with a 6 db. attenuation rate the width of the excursion will increase by 12 db.

One reason why the width of the excursions between responding and not responding have been subject to such an intensive study is because of

Békésy's (op. cit.) suggestion that they could be used clinically to test for recruitment. Békésy presented examples of very narrow excursions obtained from patients suffering from recruitment-types of perceptive deafness. However, Epstein (op. cit.) has pointed out that there definitely seemed to exist "narrow swingers" and "wide swingers." Although these only represent the limits of normality, Epstein points out that judging from their excursions the narrow swingers would be classified as suffering from auditory impairment.

Békésy's suggestion that the size of the excursions is indicative of recruitment has been supported by Reger (op. cit.) Lunborg (1953) and Meurman (1954). However, Hirsh, Palva and Goodman (1954), Palva (1954), Elliott, Riach and Silbiger (1962) have all disagreed with this suggestion. They suggest that the size of the excursions is not indicative of recruitment, but it is simply a measure of the difference limen for intensity or of the variability of results around the absolute threshold. Landes (1958) has to some extent resolved the controversy. He found that if the excursions were measured in loudness units (phons) rather than intensity units (decibels), then the excursions correlated more highly with recruitment as diagnosed by normal clinical tests. However, he noted that "notwithstanding the significant differences in group means it proved particularly difficult to assign individual subjects to the normal or recruiting groups on the basis of measurements from standard automatic audiometry."[1]

A consideration of data from other studies seems finally to resolve the controversy. Although recruitment and the difference limen for intensity are closely related (see Hirsh, 1952, chapter 8), Hirsh, Palva and Goodman (op. cit.) point out that recruitment is greater at the lower speech frequencies, whereas the difference limen for intensity is greater at the higher speech frequencies. Harbold and O'Connor (op. cit.) have shown that as the test frequency is increased, there is a trend to wider excursions as indicated in the higher standard deviations obtained. They conclude that since the width of the

[1] Standard automatic audiometry means using a db. rather than a phon measure.

excursions is greater at the higher frequencies, it probably does measure recruitment and not the difference limen for intensity. The above findings do not invalidate clinical tests such as those of Luscher and Zwislocki (1948 and 1949) and Denes and Naunton (1950). These workers utilize changes in the difference limen at a constant frequency to measure recruitment. Hence, frequency relationships will not interfere with any diagnostic findings.

Békésy audiometry seems to display the normal phenomenon that pulsed tones produce lower thresholds than continuous tones (see unpublished results by Rosenblith and Miller, reported in Hirsh, 1952, page 102). Corso (1958) Jerger and Carhart (1958) have both confirmed this result, using the Békésy technique. Harbold and O'Connor (op. cit. disagreed with these results and found that pulsed tones resulted in higher threshold values. However, these latter results can be critisized since they used an analysis of variance technique which failed to correct for initial differences in the data arising from other variables, such as the rate of attenuation and whether the frequencies were measured in an ascending or in a descending order.

An important phenomenon associated with the Békésy technique appears to have been completely ignored. Békésy noted in his original paper that when a subject traced his threshold continuously at one frequency for a fifteen minute period, then slow oscillatory changes of the order of 5 db. occured in the threshold value. Epstein and Schubert (1957) also refer to these changes. Similarly Oldfield (1955) has stated that the differential threshold for intensity "shows irregular fluctuations in time," when measured using the Békésy technique. It would appear that in experiments on TTS, these might seriously affect the results obtained. However, all workers who have used the technique whether in work on TTS or in studying other phenomena have completely ignored this phenomenon. This may be because it does not occur with the shorter periods of testing. However, no published information confirms this. Consequently a series of lengthy control experiments was undertaken as a preliminary to the present study. These were designed to study these slow oscillatory threshold changes.

Despite the comparatively recent introduction of the Békésy method, we can conclude that its usefulness is no longer questioned. However, at present we have only a limited amount of information about the effect of the various experimental parameters on thresholds recorded using the technique. It seems probable that the width of the excursions between responding and not responding to the tone measure recruitment, but the evidence for this is not conclusive. There is virtually no knowledge of other psycho-physical aspects of the method. The method produces variations in the mean threshold of approximately 5 db., but how this compares with threshold variations produced by other methods is not known.

PART 2.

EXPERIMENTAL DESIGN AND RESULTS.

CHAPTER Vll

EXPERIMENTAL DESIGN

(a) Apparatus : Basically the apparatus consisted of a Marconi oscillator, (Type TF894A), a Wein Bridge oscillator,[1] three Advance low frequency attenuators, (Type A64), a Marconi attenuator,(Type 338C), a change-over switch, a Gardners transformer,(Type GR 11471) and a monaural standard earphone manufactured by Standard Telephones and Cables,(Type 4026A). Full technical specifications of the instruments used are given in Appendix 1. The arrangement of the circuit is shown in a block diagram in figure 2 and it can be divided into two channels. The first channel provided the test tone and consisted of the Marconi oscillator, one Advance attenuator and the Marconi attenuator. The second channel provided the stimulus tone and consisted of the Wein Bridge oscillator and two Advance attenuators. The output from either channel could be fed independently into the earphone by means of the change-over switch and the transformer.

In the first channel the Marconi attenuator was adapted to provide a subject or experimenter controlled source of attenuation. How this was achieved is indicated in plate Vl and full technical details are given in Appendix 11. By the use of gears and by varying the speed of the driving motor the attenuator could be adjusted to provide rates of attenuation of 0.5, 1.0 and 1.5 db. / second. Two switches varied the amount of attenuation provided by the instrument. One was controlled by the subject and the other was controlled by the experimenter. The switches were arranged in parallel and so worked independently of each other. If either of the switches was closed the drive motor was activated and the amount of attenuation provided by the attenuator increased. When the closed switch was opened, then direction of the motor drive was automatically reversed and the amount of attenuation provided by the attenuator decreased. When the extremes of the attenuation available were reached, the drive motor automatically switched itself off at the lower extreme or at the upper extreme rapidly reversed its direction and hunted

[1] This was constructed from a circuit published by Williamson (1956).

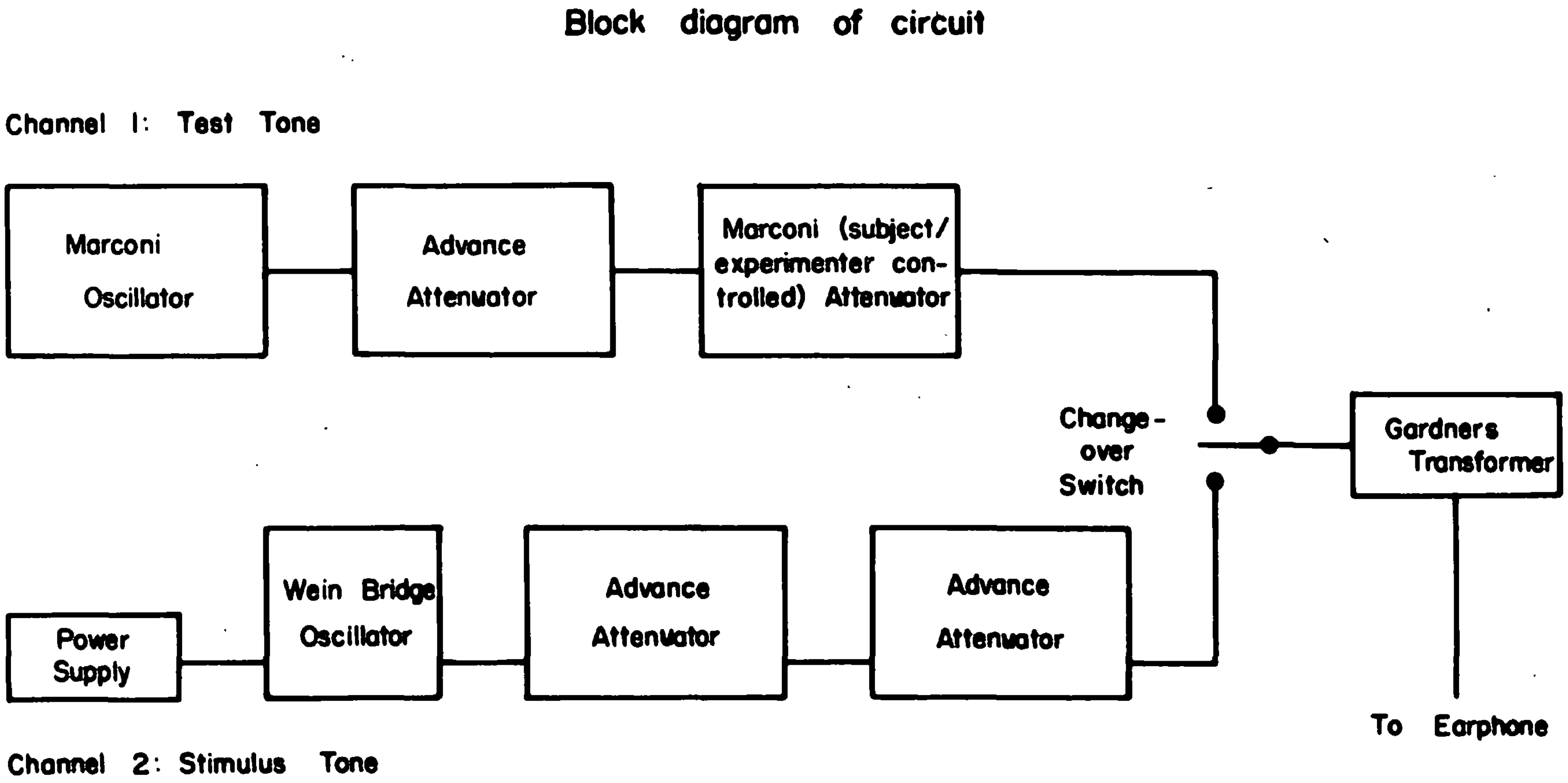


Figure 2. Block diagram of circuit used in the TTS experiments.

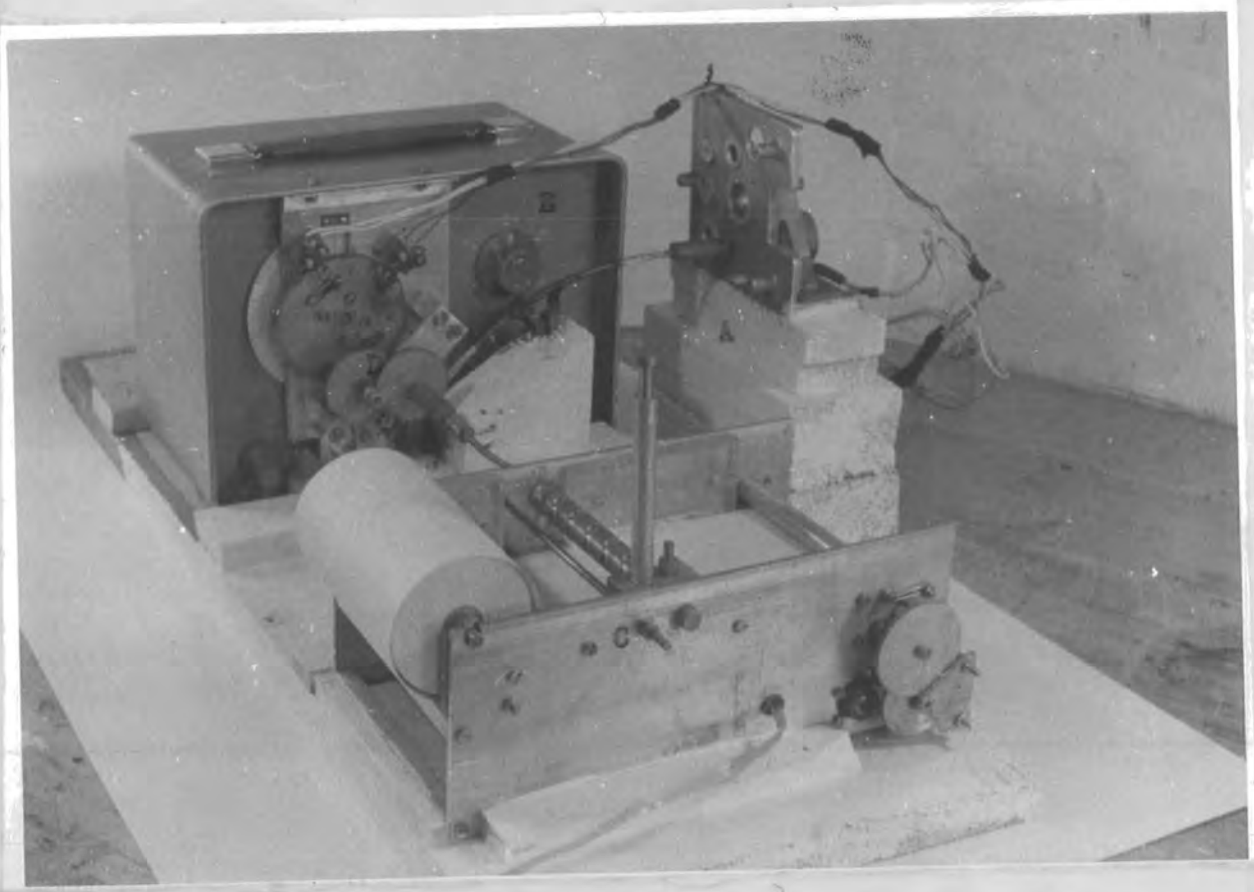


PLATE VI

Photograph of Marconi Attenuator adapted as a subject/experimenter controlled attenuator.

A : DRIVE MOTOR

B : LIMIT-SWITCHES

C : RECORDING APPARATUS

D : GEARING ARRANGEMENT

E : BASIC ATTENUATOR

backward and forwards. This prevented the attenuator being driven beyond its limits and so damaging the instrument. Any alterations in the settings of the attenuator were automatically and continuously recorded on a strip of paper 4½ inches wide moving at a constant speed of 1 inch per minute. Figures 5a, 5b and 5c (see page 67) are examples of the records obtained in this manner.

The standard earphone was calibrated at the National Physical Laboratory, Teddington and its intensity response re dynes / cm^2 was known at fixed frequencies ranging from 125 to 8000 cps. The calibration chart for the earphone is given in Appendix 111. From a knowledge of the attenuator settings and by reference to the calibration chart, the intensity of a given tone could be calculated. Alternatively, by pre-setting the attenuators the intensity of a tone could be adjusted to any required value within the range of the attenuator settings.

Testing was carried out in a specially constructed cubicle built from brick, wood, fibre glass and acoustic tiles. A plan of the cubicle is given in figure 3. It can be seen from the plan that the walls consisted of a 4 inches thickness of brick, a 6 inches thickness of packed fibre glass and a ¾ of an inch thickness of acoustic tile. The roof was similarly constructed but had an additional air space ranging from 1 foot to zero inches in thickness. The internal walls and ceiling were constructed on a wooden frame which was structurally separate from the external walls. The room had double doors. The external door was constructed from plywood mounted on a wooden frame. The internal door consisted of a ¾ of an inch thickness of acoustic tile, a 1 inch thickness of fibre glass and a second ¾ of an inch thickness of acoustic tile. An air space of 6 inches existed between the two doors. The effectiveness of the sound insulation will be discussed later (see page 187).

A signal light system enabled the subject and experimenter to communicate with each other when the subject was in the test room. As well as the subject's part of the signal light system, the following

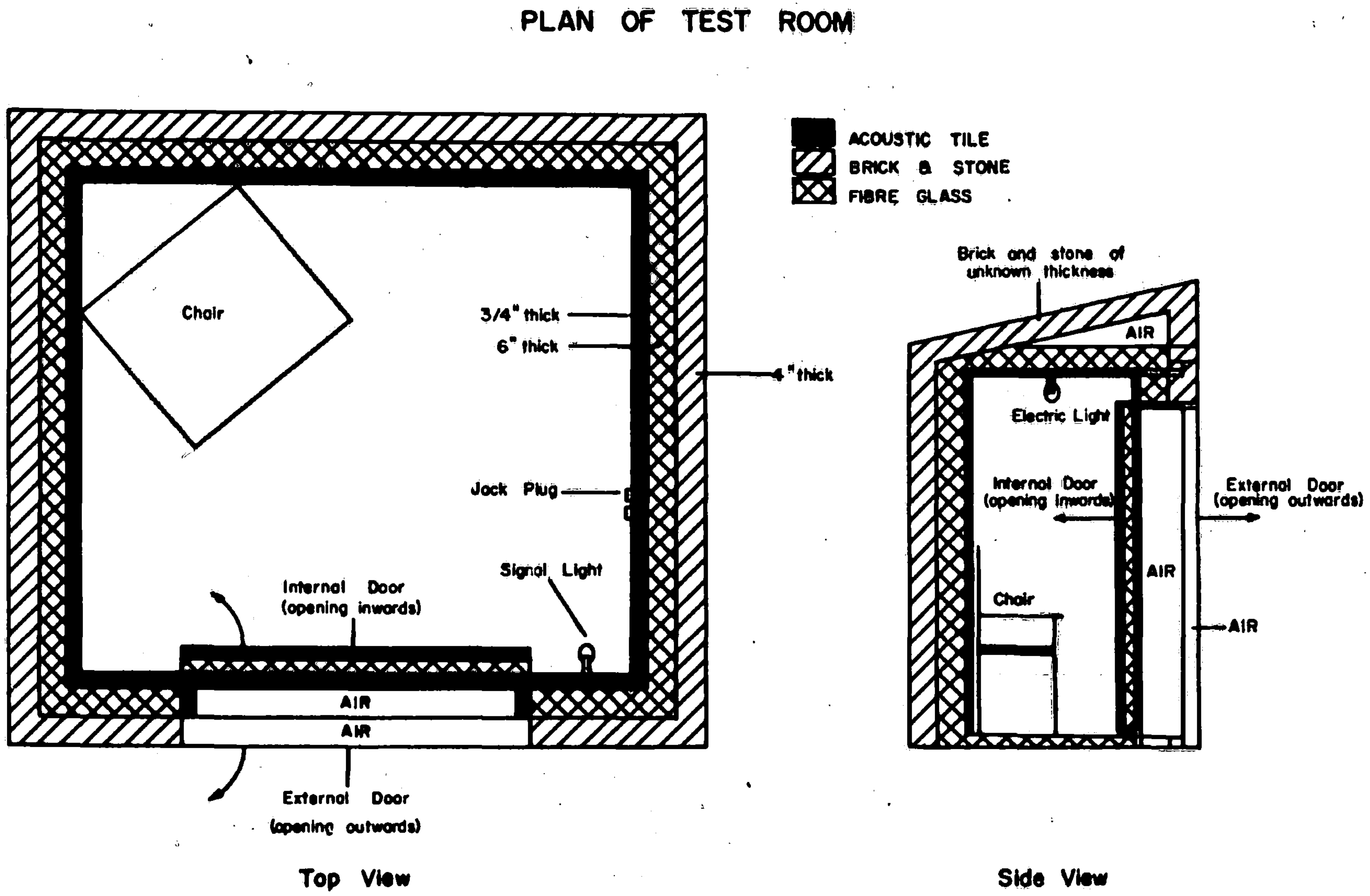


Figure 3. Plan of test cubicle in which the subject was situated.

equipment was situated inside the test toom :

(i) A chair for the subject to sit on.

(ii) A push-button switch attached to the arm of the chair which controlled the subject / experimenter controlled attenuator.

(iii) The monaural standard earphone.

(iv) A wall socket into which the earphone could be plugged.

(v) A 60 watt illumination light situated in the roof.

(vi) A carpet.

No ventilation was provided in the room because of the great difficulty in providing ventilation which was adequately sound-proofed. However, a high powered electric blower was available to clear the air in the room when required.

(b) <u>Subjects</u> : Twenty-four subjects were used in the experiments. Six were female and eighteen were male. The subjects were divided up into groups of six for use in different parts of the study. All the subjects were young (18-23 years old) undergraduate members of the department of Psychology in the University of Durham. The only information they were given concerning the experiments was that they were to study changes in the threshold of hearing resulting from stimulation of the ear by preceding sounds and that there was no danger of any permanent injury. The predominance of male subjects was not thought to be important since Ward, Glorig and Sklar (1959) have shown that there is no significant difference in susceptibility to TTS between men and women. Prior to the experiment the subjects were carefully screened to eliminate any subjects suffering from abnormalities of hearing and/or abnormal susceptibility to TTS.[1] Two tests were used for this purpose. They were :

(i) A modified method of limits determination of pure tone

[1] This was done so that there would be no danger of susceptible subjects suffering from permanent losses of hearing acuity.

thresholds and a comparison of these thresholds with the data of Sivian and White (1933).

(ii) Carhart's (1957) test, which utilizes TTS to test for recruitment.

Full details of the screening procedure and the results obtained are given in Appendix 1V.

(c) General Procedure. The subjects attended in pairs for test sessions lasting from 1½ hours to 2 hours. The sessions were sub-divided into approximately 15 minute test periods and while one subject was being tested the other subject rested. Sataloff (1957) and Glorig (1958) have suggested that fifteen minutes is an adequate rest period before administering audiometric tests to workers in noisy industries. This they claim allows for recovery from TTS. Since the exposures used in the experiment were only of very short duration compared with industrial exposures, a fifteen minute recovery period was thought to be adequate. A control experiment to check this was performed and will be described later. The subject/experimenter controlled attenuator was set to an attenuation speed of 0.5 db/second.

(d) Training : Prior to the commencement of the experiments, the subjects were first given training in the technique of threshold measurement using the Bekesy method. This training had three purposes :-

(i) It familiarised the subjects with the manipulation of the switches and the wearing of the earphone.

(ii) It familiarised the subjects with the tones used and with the detection of such tones at very low intensities.

(iii) It eliminated practice effects in the experiment proper.

The subjects were each given two practice sessions of 1½ hours and two of the subjects who had difficulty with the technique were given a third practice session.

Prior to the first practice period of the first test session, the following instructions were given to the subjects :

"When you enter the cubicle sit down, place the earphone on your left (right) ear and adjust it until it is comfortable." (During these instructions the subjects were shown the cubicle and the earphone situated in the cubicle). "Once you have adjusted the earphone so that is is comfortable *do not interfere with it* until you come out of the cubicle at the end of the test session. In the earphone you will hear a sound similar to the sound of a tuning fork. On the right hand side of your chair is an arm with a push-button switch attached to it. If you press this button, the tone will gradually decrease in loudness until you cannot hear it any more. If you then release the button, the tone will gradually increase in loudness until you can hear it again. What I want you to do is to fluctuate between just not hearing the tone and just hearing it, by pressing and releasing the button. If you press the button the tone automatically decreases in loudness; if you do not press it, the tone automatically increases in loudness. So when you think you *can hear the tone, you press the button and when you think you cannot hear the tone, you release or do not press the button*. Do you understand?"

The subject was then allowed to ask questions but the replies were always given within the framework of the above instructions. They were also allowed to listen for a few seconds to one of the tones being tested and told that the sound they would be listening to would "be similar only much quieter." This procedure was repeated for the second practice period but thereafter, the subject was simply instructed to "trace your threshold as in the previous trials." The subjects traced their threshold for fifteen minute periods with a test period of fifteen minutes between each practice period. Practice was given with frequencies of 1000, 1500, 2000, 3000, 4000 and 6000 cps. The order of training was randomized for different subjects.

(d) *Stimulus Tone variables* : Davis, Morgan, Hawkins, Galambos and Smith (1950) and Hood (1950) have shown that with high intensity stimuli, maximum TTS is produced at a frequency half an octave above the stimulus tone frequency. Hence throughout the course of these experiments, the test tone was always maintained at a frequency half an octave above the particular stimulus tone under investigation. The procedure followed in each experimental trial was :

(i) A pre-exposure period during which the subject traced his threshold for a given test tone for two minutes.

(ii) An exposure period during which the subject listened to a pre-determined stimulus tone.

(iii) A post exposure period during which the subject traced his threshold for the given test tone for a further three minute period.

The following instructions were given to the subject on the first and second experimental trials :

> "On entering the cubicle, I want you to trace your threshold as before. However, after you have been doing this for about two minutes, the signal light will go out and the tone will change. When this happens, I want you to stop tracing your threshold. The second tone will be much louder than the first and while it is on you are not required to do anything. After a given period, the signal light will come back on and the tone will revert to the original tone. I want you to recommence tracing your threshold when this happens. Remember when the signal light is on, you must trace your threshold and when it is off, you must not trace your threshold."

Two groups of six subjects were used in these experiments and they were subjected to the following experimental conditions:

(i) Condition A: TTS was recorded for a fixed stimulus frequency (1000 cps), with fixed stimulus intensities

(70, 90 and 110 db. re 0.0002 dynes / cm^2) and at varying stimulus durations (0.5 to 7 minutes in half minute intervals).

(ii) Condition B: TTS was recorded for a fixed stimulus frequency (1000 cps), with varying stimulus intensities (70 to 120 db. re 0.0002 dynes / cm^2 in 5 db. steps) and at fixed stimulus durations (1, 2 and 3 minutes).

(iii) Condition C: TTS was recorded for varying stimulus frequencies (500, 750, 1000, 1500, 2000, 2500, 3000, 3500, 4000 and 6000 cps), with fixed stimulus intensities (70, 90 and 110 db. re 0.0002 dynes / cm^2) and at fixed stimulus durations (1, 2 and 3 minutes).

In each of the three conditions, the order of testing of the variables was randomized. One group of the subjects was used for Conditions A and B and the other group was used for Condition C.

(e) Test Tone Variables : As in the experiments on the stimulus tone variables the procedure involved a pre-exposure, an exposure and a post-exposure period and the instructions given to the subject were exactly the same. Stimulus tones of 1000, 2000, 3000, 4000 and 6000 cps were used and their effect on various test frequencies investigated. Since the subject / experimenter controlled attenuator used a continuous tone, it was not possible to investigate the effect of test tone duration. Each stimulus tone was used under four different conditions. These were:

(i) With a stimulus intensity of 70 db. and a stimulus duration of 1 minute.

(ii) With a stimulus intensity of 70 db. and a stimulus duration of 3 minutes.

(iii) With a stimulus intensity of 110 db. and with a stimulus duration of 1 minute.

(iv) With a stimulus duration of 110 db. and with a stimulus duration of 3 minutes.

TTS was measured for each of the five stimulus tones under each of the four conditions, using test tone frequencies of 500, 1000, 1500, 2000, 3000, 4000, 6000 and 8000 cps. The order of testing of the test tones and the associated stimulus conditions was randomized. One group of six subjects was used for these experiments.

(f) Recovery from TTS : Two separate experiments were carried out on recovery from TTS. These were :

(i) An experiment studying the time taken for the threshold to recovery to normality.[1]

(ii) A study of all the material gathered in sections (d) and (e) on the stimulus and test tone variables.

The apparatus used in the first experiment on the time for the threshold to recovery to normality, differed slightly from the apparatus described earlier. However, apart from the non-inclusion of the subject / experimenter controlled attenuator it was essentially the same as that used in the first (test tone) channel of the previous apparatus. Full details of the apparatus and the four subjects used are reported in an article by Rodda (1962). As in the experiments on the stimulus and test tone variables, the procedure involved a pre-exposure, an exposure and a post-exposure period. However, in this experiment, the stimulus and test tone frequencies were always the same for any one experimental trial.

The threshold in the pre-exposure period was determined using a modified method of limits. It was always determined in an ascending direction and a hundred per cent response criterion was always used. In this period the intensity of the tone was adjusted to about 20 db. below the threshold for the subject at the particular test frequency being used. The tone was pulsed with equal on-off times of approximately 0.5 seconds. The intensity was increased in 1 db. steps until the subject responded to ten consecutive applications of the tone at a given intensity. At this point the intensity of the tone was recorded and this was taken as a measure of the subject's threshold. During the exposure period the

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[1] The raw data presented in this experiment was used in a thesis presented in part requirements for the degree of B.Sc. at the University of Durham. However, the treatment of the data in this thesis is completely different.

tone was continuously applied to the ear of the subject for a period of one minute. After this, the tone was cut off and its intensity adjusted to the threshold value determined in the pre-exposure period. During the post-exposure period the tone at threshold intensity was again pulsed and applied to the ear of the subject. The time from the cessation of the stimulus tone to the subject's first response to the test tone in the post-exposure period was recorded. This gave a measure of latent time. In order to work to the hundred percent threshold criterion, the tone was applied to the ear of the subject for a further period following upon his first response. If the subject failed to respond to the consecutive applications of the tone, the result was discarded and the trial repeated later in the experimental period. Subjects were given practice sessions using a stimulus / test frequency of 1000 cps.

Frequencies of 1000, 2000, 4000 and 8000 cps were used in the experiment. Each frequency was tested in turn but the order of testing was randomized for the different subjects. Half of the subjects were tested on the right ear and half on the left ear. The intensity of the stimulus tone was varied from 10 to 110 db. re the subjects threshold in 10 db. steps. The actual physical intensities represented by these variations, ranged from 18.1 to 100.8 db. re 0.0002 dynes / cm^2. Three trials were given at each stimulus intensity and the order of testing of the different trials and the different intensities was randomized. A mean latent time for each stimulus intensity was obtained by taking the mean of the trials at that intensity.

The second series of experiments on recovery utilized the data collected in the experiments on the stimulus and test tone variables. These necessitated the recording of threshold recovery for a period of three minutes following the cessation of the stimulus tone. A total of 1950 results were obtained as follows :

(i) Stimulus Tone variables
    Condition 'A': 42 results for six subjects
    Condition 'B': 33 results for six subjects
    Condition 'C': 90 results for six subjects

(ii) Test Tone variables
    160 results for six subjects

Each of the individual results were studied to ascertain whether recovery was diphasic, whether recovery showed a sensitization period and whether bounce was higher than initial TTS. The mean of the first two transition points in the post-exposure period was also recorded and this was taken as a measure of initial TTS. Finally the difference between the threshold after its initial return to normality and its subsequent highest value was calculated. This was recorded as a measure of the amount of bounce.

(g) Control Experiments : Four control experiments were carried out. Their function was to test :

(i) Whether the recorded TTS could result from chance variations in threshold measurements.

(ii) Whether diphasic recovery from TTS could result from the use of the Békésy method of threshold tracing.

(iii) To test whether TTS was additive over the periods of time involved in the experiment.

The experiments were as follows :

(i) Experiments in which the stimulus tone was replaced by a period of silence.

(ii) Experiments in which variations in threshold using the Békésy method were compared with variations in threshold using threshold measurements obtained by the method of limits.

(iii) Experiments which compared the tracing of thresholds, using the Békésy method, for short periods and for long periods..

(iv) Experiments to test whether TTS produced additive effects over the 1½ to 2 hour test session.

(v) Experiments to measure the ambient noise level in the specially constructed sound-proof room.

The procedure used in the first series of experiments, in which the stimulus tone was replaced by the period of silence, was exactly the same as the procedure adopted in studying the stimulus and test tone variables. To avoid any "expectancy" or other similar factors affecting the results, these experiments were carried out in conjunction with the experiments on the test tone variables. The same group of subjects were used and the control trials were introduced into the randomized order of testing of the test tone variables. The subjects were not informed that in certain cases the stimulus would be replaced by a period of silence. However, after the first control trial they usually commented on the absence of the stimulus tone. In this case they were informed that this was deliberate and they were not to worry about it. Three periods of silence (1, 2 and 3 minutes) were used with test frequencies of 1000, 4000 and 6000 cps. This gave a total of nine control results for each of the six subjects used.

Two subsidiary experiments were carried out to compare threshold variations using the Békésy method with threshold variations using a modified method of limits. These were :

(i) A direct comparison of the two methods.

(ii) Experiments on recovery from TTS in which threshold measurements were obtained using a modified method of limits instead of the Békésy method.

The procedure adopted in threshold measurements using the modified method of limits necessitated the use of the first channel of the apparatus. However, instead of the settings of the subject / experimenter controlled attenuator being controlled by the subject, they were controlled by the experimenter in the following manner :

(i) Prior to testing the experimenter adjusted the intensity of the tone to a level about 10 db. above the subject's threshold for the particular test tone under investigation.

(ii) The experimenter closed the switch activating the subject / experimenter controlled attenuator and allowed the intensity of the tone to be gradually reduced by 20 db. He then opened the switch and allowed the intensity of the tone to be gradually increased by 20 db.

(iii) The first and second procedures were alternated so that the intensity of the tone gradually decreased and increased in loudness over a 20 db. range.

(iv) Initially the experimenter might vary slightly the extremes of the 20 db. range so that the subject's mean response fell approximately at the middle of the range.

Each intensity at which the subject changed his response from hearing to not hearing and vice-versa was recorded. These points were equivalent to the similar transitions obtained using Békésy audiometry.

The choice of a 20 db. intensity range was determined after reference to the data of Steinberg and Munson (1936). They give ± 3.1 db. as the standard deviation of variations in the response of an individual subject to pure tone, near 'threshold' stimuli. Hence, on this figure 99.8% of 'threshold' responses would fall within a range of 18.6 db., i.e. $\pm 3\sigma$. That this range was sufficient is indicated by the fact that the subjects always responded to the tone at the upper limit of the range and never responded to the tone at the lower limit of the range.

The comparison of variations in the threshold using Békésy audiometry and variations in the threshold using the modified method of limits was carried out in the following way:

(i) The subjects traced their threshold for one 15 minute period at frequencies of 1000, 1500, 2000, 3000, 4000 and 6000 cps, using the Békésy technique.

(ii) The subjects traced their threshold for one 15 minute period at a frequency of 1500 cps using the modified method of limits technique.

The single frequency of 1500 cps used in (ii) was chosen after the analysis of the data collected in (i) had shown that variations in threshold were maximum at this frequency, using the Békésy technique.

The procedure adopted in the control experiment on recovery from TTS utilized threshold measurements obtained with the modified method of limits. Exactly the same procedure was used as in the experiments on the stimulus and test tone variables except that :

(i) The pre-exposure and post-exposure threshold measurements were made using the modified method of limits and not the Békésy method.

(ii) Instead of using a 20 db. range for the method of limits, the limits taken were + 3 db. and - 3 db. above and below the intensities at which the subject changed his response from not hearing to hearing and vice-versa.

(iii) The onset or cessation of the stimulus tone was not signalled since the signal-light system was already being used by the subject.

The slight further modification of the method of limits described in (ii) was incorporated to increase the number of threshold responses obtained in the pre-exposure and post-exposure test periods.

Testing was carried out with a stimulus tone of 1000 cps at intensities of 70, 90 and 110 db. with stimulus durations of one, two and three minutes. TTS was measured using a test-tone of 1500 cps., i.e. a tone half an octave above the stimulus tone.

The next control experiment compared the tracing of thresholds for short periods and for long periods using the Békésy method. The same group of subjects were used as for the previous control experiments. They traced their thresholds for 15 minute periods at frequencies of 1000, 1500, 2000 and 3000 cps using the Békésy method. However, instead of tracing continuously for 15 minutes, they traced for 3 minutes and rested for 2 minutes. This cycle occured three times in the 15 minute period. The tracings obtained under these conditions were compared with their tracings obtained above, i.e. when the subjects traced continuously for the full 15 minute test period. Unfortunately, two of the subjects used in the original Békésy experiments were not available for testing on this latter procedure; and hence results were available for only four of the subjects.

To control for additive effects of TTS the following procedure was adopted. At stimulus frequencies of 1000, 2000 and 3000 cps, TTS after exposure to a 110 db. stimulus tone of duration three minutes was recorded at the beginning and at the end of a test session. The mean shifts at the beginning and at the end of the test session were compared for each frequency. This experiment was designed to confirm that the 15 minute rest period during the test sessions was sufficient to allow not only recovery from TTS but also recovery from any heightened susceptibility to stimulus exposures.

In the final control experiment, recordings were made of the overall noise level in the test cubicle using a Dawe Sound Level Meter (type 1400E) with the A, B and C frequency weightings. Measurements were taken at fifteen minute intervals for three three hour periods chosen to coincide with usual test times. Recordings were also taken at one minute intervals for three fifteen minute periods at the beginning, the middle and the end of these test times.

CHAPTER V111

RESULTS OF THE EXPERIMENTS ON THE STIMULUS AND TEST TONE VARIABLES.

(a) Training :

A study of the comments and tracings of the subjects during the training sessions revealed that a great many of them initially had difficulty in tracing their threshold using the Békésy procedure. The main difficulty seemed to be in deciding whether they could or could not hear the tone. The subjects said that in many cases they were not sure whether or not the tone was present. However, this difficulty was usually overcome in the first or second fifteen minute training period.

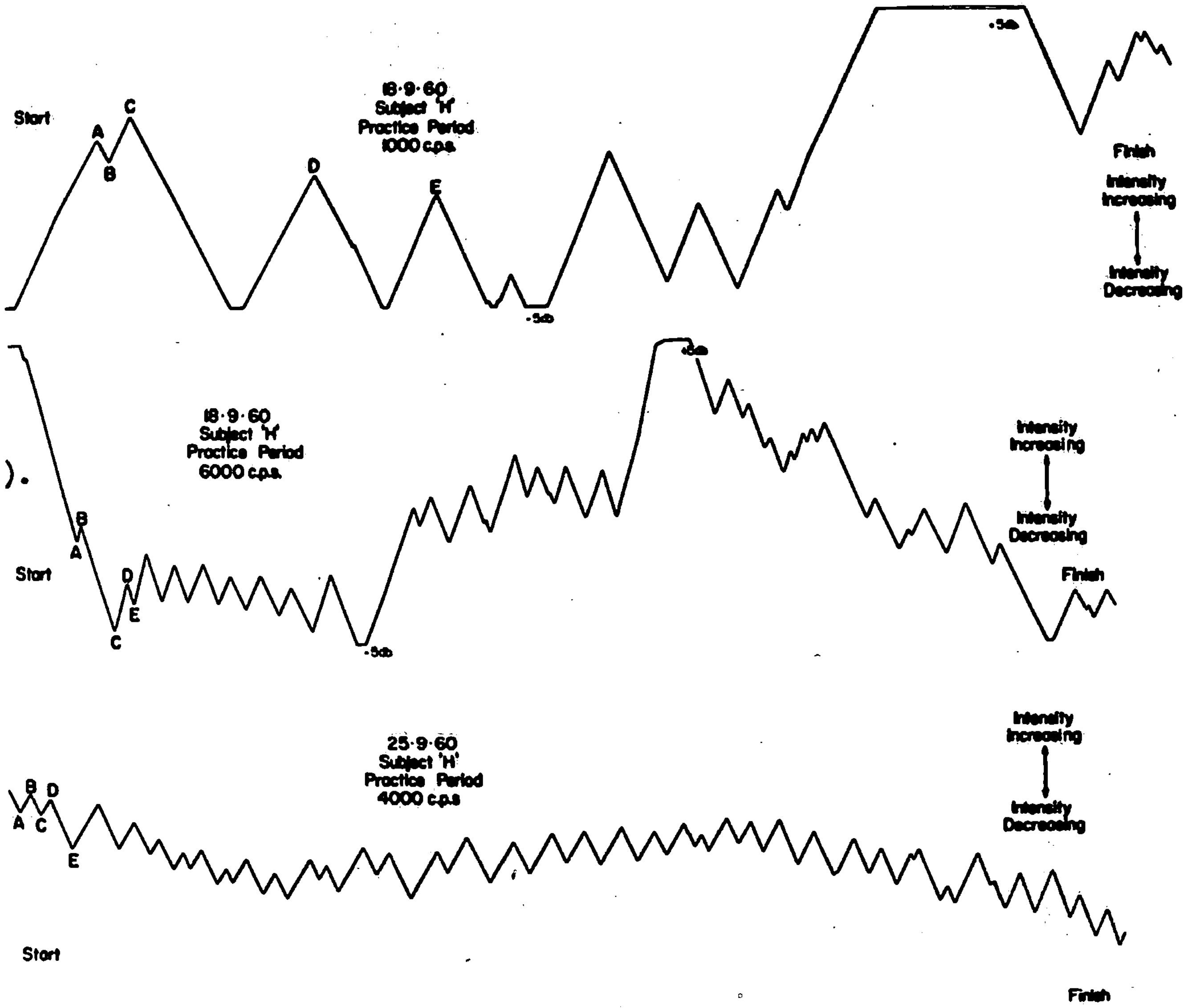
Typical results obtained during the first, third and final training periods are shown in figures 4a, 4b and 4c. These figures are copies of the recordings obtained from the subject/experimenter controlled attenuator, using the Békésy method of threshold tracing. In them, time reads from left to right and attenuation from top to bottom. Thus a top to bottom movement of the recording indicates a gradual reduction in the loudness of the tone and a bottom to top movement indicates a gradual increase in the loudness of the tone. The values written on the edge of the recordings, e.g. + 5 db. on figures 4a and 4b, indicate that the basic intensity level of the tone was altered by that amount. This was done when the subject reached the extremes of the subject/experimenter controlled attenuation range and hence was not able to increase or decrease the intensity of the tone. The points marked A, B, C, D and E and all such similar points are transition points, i.e. points at which the subject changes his response from hearing to not hearing and vice-versa. Inspection of the figures reveals that as training progressed, there is a gradual diminution of the following :

(i) The rapid and large changes in the mean point of fluctuation.

(ii) The rapid and large changes in the range between successive transition points.

(iii) The constant need to alter the attenuator settings to prevent the subject stopping at the extremes of the

Figure 4: Scaled copies of typical Békésy tracings obtained during the training periods. Time is measured from left to right (scale 1" to 2.2 min.) and intensity from top to bottom (scale 1" to 14.4 db.).



subject/experimenter controlled attenuator.

The final training period (e.g. figure 4c) produced a recording that maintained a fairly consistent mean point of fluctuation and a fairly consistent range of fluctuation. The aperiodic, cyclical changes in the point of oscillation will be discussed later. These results were typical for all subjects.

(b) Stimulus Tone Variables.

Figures 5a, 5b and 5c are copies of typical tracings obtained during the TTS experimental trials. On the tracings are shown the pre-exposure, exposure and post-exposure periods. The pre-exposure and post-exposure thresholds were calculated by taking the mean of the transition points, in each period, at which the subject changed his response from hearing to not hearing and vice-versa. TTS on any one trial was measured by calculating the difference between these two thresholds.

Three experiments were carried out to study the stimulus tone variables. These were previously listed (see pages 55 to 56) as follows :

(i) Condition 'A' : TTS was recorded for a fixed stimulus frequency (1000 cps), with fixed stimulus intensities (70, 90 and 110 db. re 0.0002 dynes / cm^2) and at <u>varying stimulus durations</u> (0.5 to 7 minutes in half minute intervals).

(ii) Condition 'B' : TTS was recorded for a fixed stimulus frequency (1000 cps), with <u>varying stimulus intensities</u> (70 to 120 db. re 0.0002 dynes / cm^2 in 5 db. steps) and at fixed stimulus durations.

(iii) Condition 'C' : TTS was recorded for <u>varying stimulus frequencies</u> (500, 750, 1000, 1500, 2000, 2500, 3000, 3500, 4000 and 6000 cps), with fixed stimulus intensities (70, 90 and 110 db. re 0.0002 dynes / cm^2) and at fixed stimulus durations (1, 2 and 3 minutes).

The results obtained in each of the experimental conditions are described in the succeeding sections.

(a) <u>Condition 'A'</u> : Means values for TTS (see figure 5) were

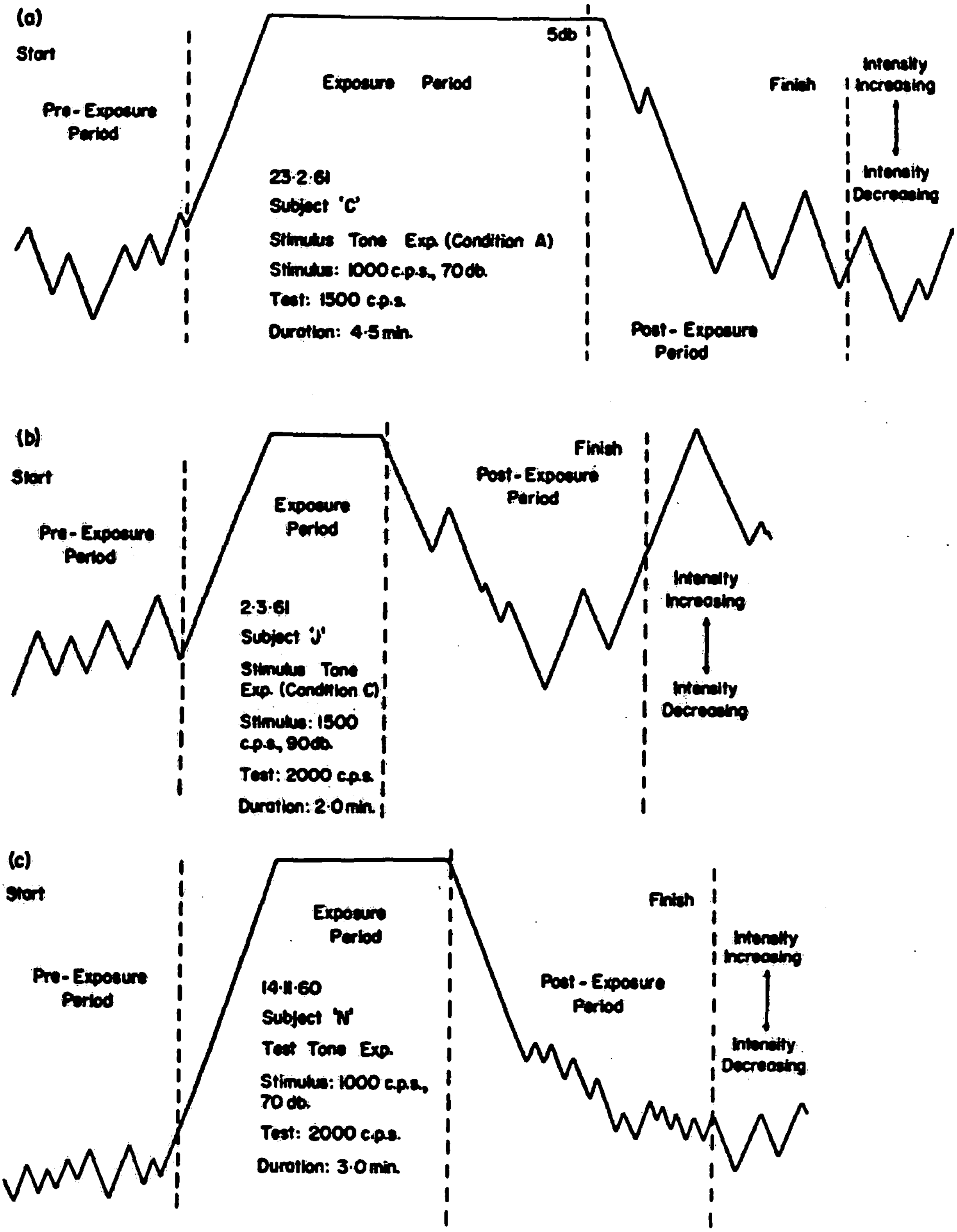


Figure 5. Scaled copies of typical tracings obtained during the experiments studying TTD as a function of the stimulus and test tone variables. (Intensity : 1 inch to 10 db., time 1 inch to 1.7 minutes).

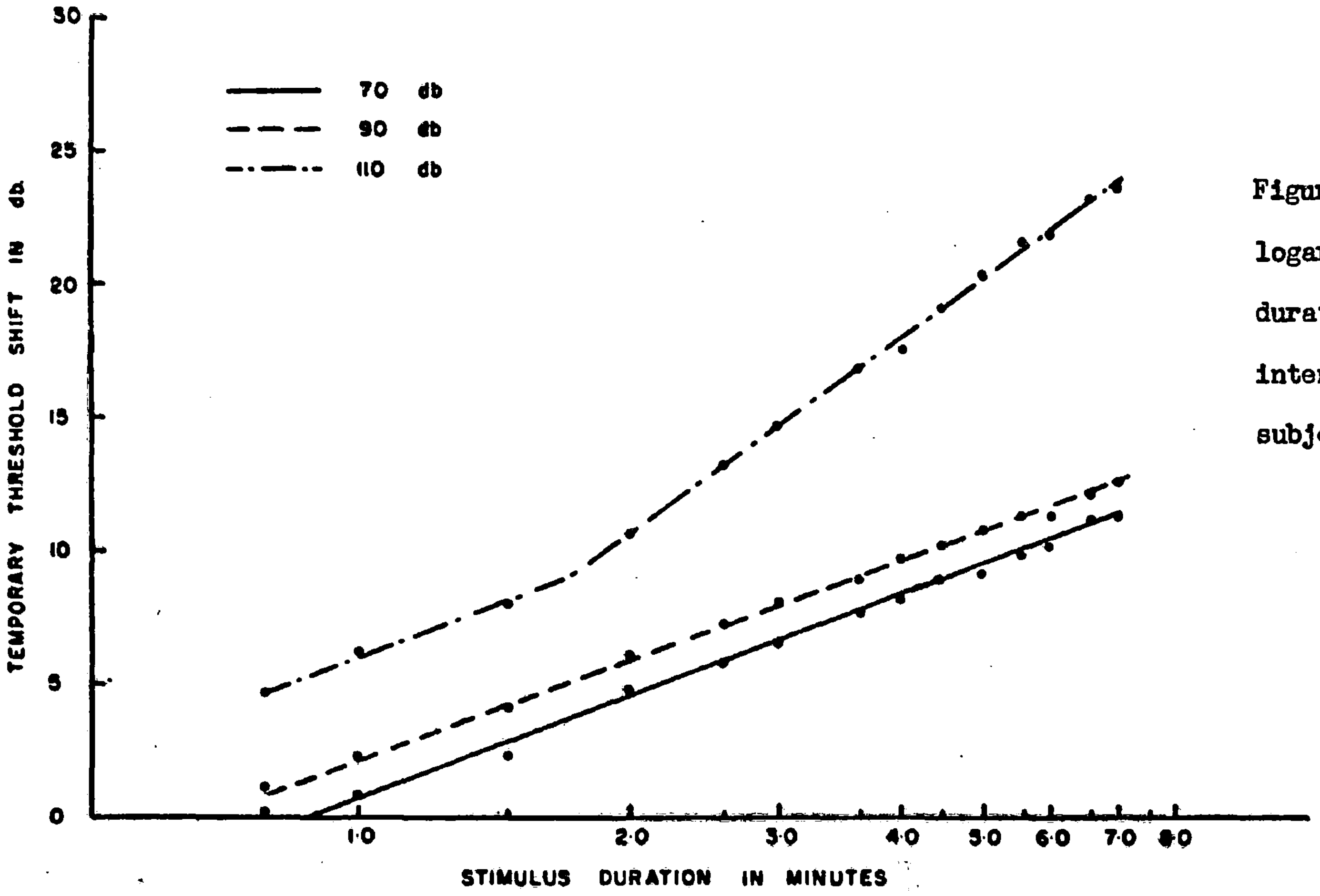


Figure 6: Graph of TTS as a logarithmic function of the stimulus duration. Parameter is stimulus intensity. Mean results for six subjects.

calculated for the six subjects used in condition 'A' at each stimulus duration and for each of the three stimulus intensities. The mean results were plotted as a logarithmic function of stimulus duration and the values are shown in figure 6. It can be seen from this figure that with stimulus intensities of 70 and 90 db. there is a linear increase in TTS with the logarithm of the stimulus duration. It can also be seen that the 70 and 90 db. lines lie approximately parallel to each other. With a stimulus duration of 110 db., there is still a linear relationship between TTS and the logarithm of the stimulus duration. However, the 110 db. line divides itself into two parts. With short stimulus durations it parallels the 70 and 90 db. lines, but as the stimulus duration is increased there is a change in the slope of the line so that it no longer remains parallel to the 70 and 90 db. lines. In figure 6 this transition occurs at a stimulus duration of approximately $1\frac{3}{4}$ minutes.

The lines shown in figure 6 were drawn merely by inspection of the data presented. To test whether these lines were essentially correct the equations of the lines of best fit were calculated using the method of least squares (see Yule and Kendall, 1950, pages 342) at the 70, 90 and 110 db. stimulus intensities. For the 110 db. line it was necessary to sub-divide the data into two sections because of the change in the slope of this line at approximately $1\frac{3}{4}$ minutes. For comparison purposes the slopes and intercepts of the lines shown in figure 6 were calculated by direct measurement. The results of these calculations are summarized in table 1 (see page 70). It can be seen from this table that there is close agreement between the theoretical values for the slope and intercept of the lines and the practical values obtained by inspecting the data and drawing in the lines accordingly. The theoretical values given in table 1 also confirm the parallelism between the 70, 90 and the early part of the 110 db. lines. The table reveals that there are only differences of 0.006, 0.014 and 0.009 between the slopes of the lines which theoretically best fit this data. The table also confirms the change in the slope of the 110 db. line. Theoretically a slope of

Table 1.

X = Stimulus duration in logarithmic units a_1 = Theoretical slope of line of best fit A_1 = Slope of line shown in figure 5

Y = Temporary Threshold Shift in db. a_o = Theoretical intercept of line of best fit A_o = Intercept of line shown in figure 5

Stimulus Intensity	Sum of X	Sum of Y	Sum of XY	Sum of X^2	a_1	a_o	A_1	A_o
70 db.	737	96.67	6005.86	44075	0.173	-2.202	0.192	-2.8
90 db.	737	115.33	7018.71	44075	0.179	-1.211	0.193	-1.6
110 db. (First Part)	64	18.8	431.80	1529	0.187	2.262	0.198	2.6
110 db. (Second Part)	673	201.7	12832.3	42545	0.359	-3.627	0.367	-4.1

Summarizes the calculations of lines of best fit for the mean data shown in figure 6.

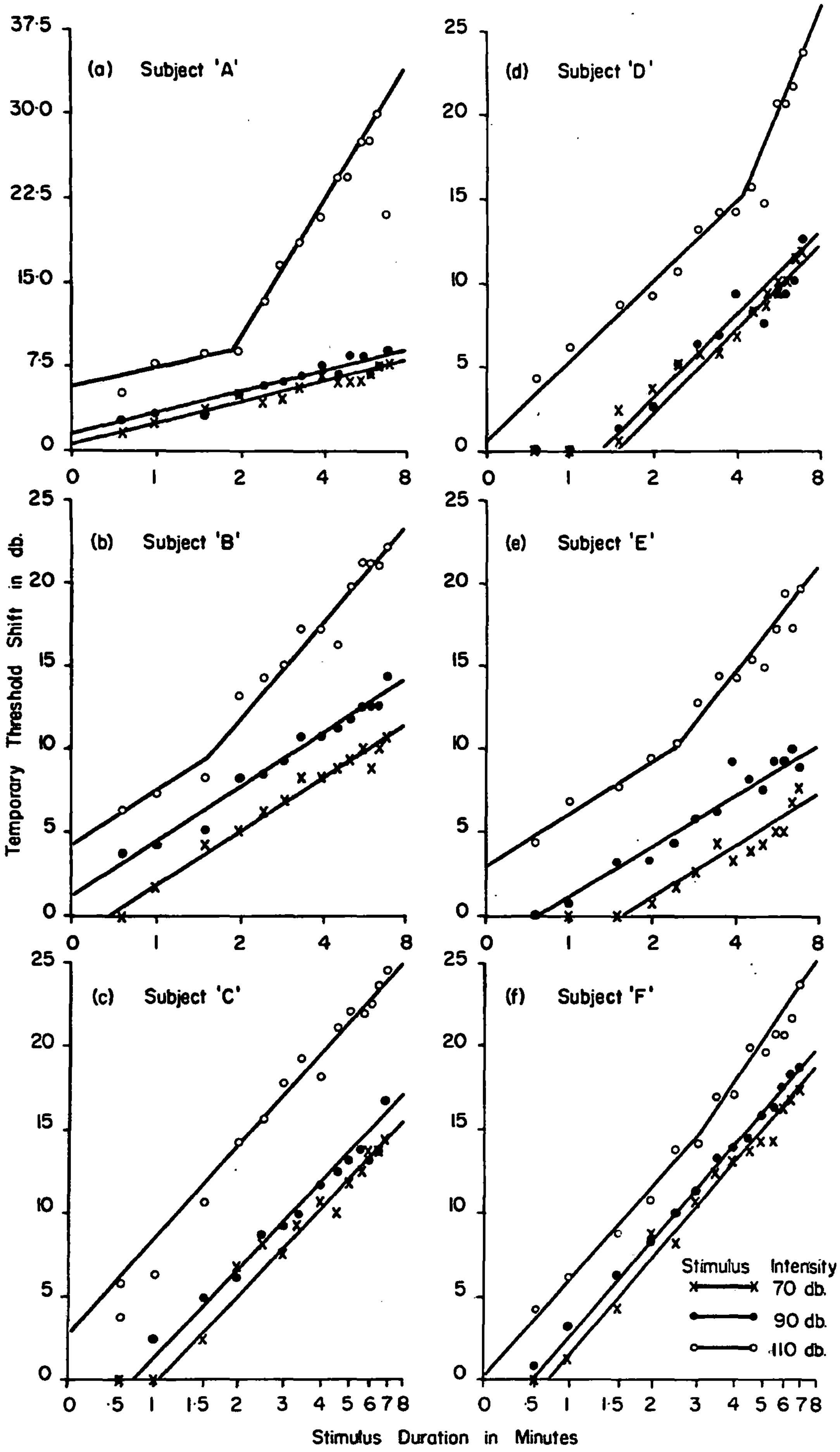


Figure 7 : Shows the individual results obtained for TTS as a logarithmic function of the stimulus duration.

0.187 best fits the first three points on this line and a slope of 0.359 best fits the remainder of the points on this line.

There was a close agreement between the individual and the mean results. The individual results are presented in figures 7a to 7f. Allowing for the greater variation of individual results, it can be seen from these figures that for five of the subjects the results are essentially the same as those obtained when mean values were taken. However, with individual subjects there is some variation in the stimulus duration at which the slope of 110 db. line changes. Figures 7a to 7f indicate that it occured for different subjects at stimulus durations ranging from approximately 1½ to 4 minutes. For one of the subjects (viz. 'C') the results are different from those obtained with the other five subjects. In the case of this subject the slope of the 110 db. line remained consistent and the 70, 90 and 110 db. lines would appear to remain parallel over the whole range of stimulus durations used in the experiment. These observations and the agreement between the theoretical lines of best fit and the lines drawn by inspection were checked, as for the mean values, by calculating the lines of best fit by the method of least squares. The results are summarized in table 11. Inspection of this table indicates that allowing for chance variation, there is a close agreement between the theoretical lines of best fit and the lines drawn by inspection. Similarly, inspection of the table justifies the above observations made concerning the individual results.

<u>Condition 'B'</u> As in condition 'A' mean results for TTS were calculated. The mean TTS's for the six subjects used in Condition 'B' at each of the stimulus intensities and for each of the three stimulus durations were calculated. Mean TTS at each stimulus duration was plotted as a function of stimulus intensity and the results are shown in figure 8. It can be seen from this figure that with stimulus durations of 1, 2 and 3 minutes, there is little increase in TTS as the stimulus intensity is raised from 70 to 95 db. Above 95 db. there is for all three stimulus durations, an increase in TTS as the stimulus intensity is further increased.

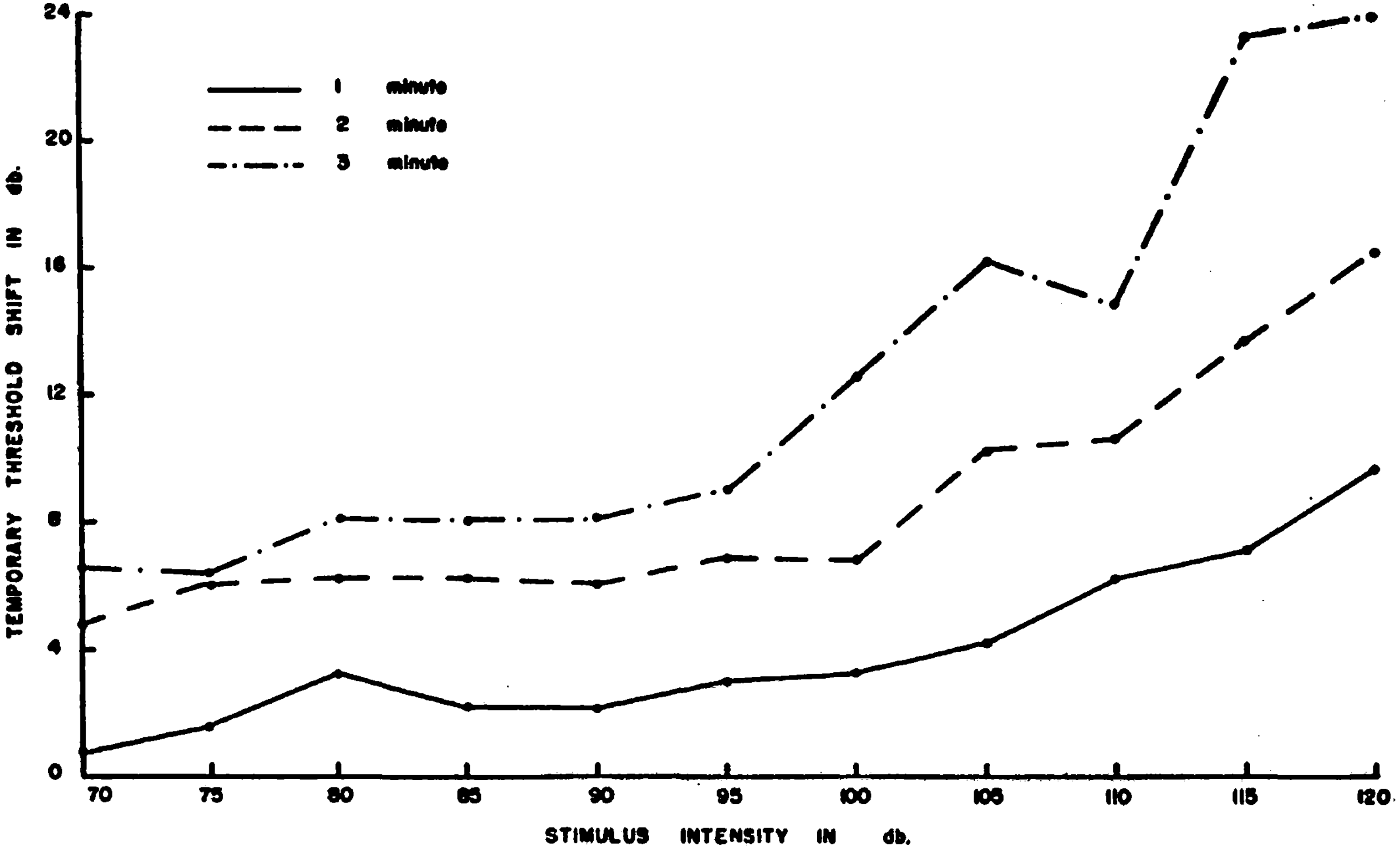


Figure 8: Graph of TTS as a function of stimulus intensity. Parameter is stimul duration. Mean results for six subjects.

Table 11

Summarizes the calculations of the lines of best fit for the individual results shown in figure 7a to 7f.

a_1 = Slope of theoretical line of best fit.

a_o = Intercept of theoretical line of best fit.

A_1 = Slope of line shown in figure 7.

A_o = Intercept of line shown in figure 7.

		Subject					
Stimulus Intensity	Variable	A	B	C	D	E	F
70	a_1	0.090	0.156	0.239	0.198	0.116	0.279
70	a_o	0.539	-1.203	-3.921	-2.892	-2.892	-3.839
70	A_1	0.083	0.162	0.214	0.215	0.150	0.283
70	A_o	0.750	-1.250	-6.321	-4.875	-4.250	-4.350
90	a_1	0.091	0.165	0.236	0.207	0.163	0.277
90	a_o	1.486	0.957	-2.647	-4.326	-2.456	-2.707
90	A_1	0.083	0.158	0.225	0.215	0.163	0.283
90	A_o	1.500	1.500	-3.85	-6.725	-2.725	-3.125
110 (first part)	a_1	0.115	0.167	0.305	0.269	0.171	0.266
110 (" ")	a_o	4.302	4.062	1.429	-3.129	2.635	0.777
110 (" ")	A_1	0.105	0.166	0.218	0.256	0.189	0.296
110 (" ")	A_o	6.000	4.25	3.75	0.500	3.738	0.250
110 (second part)	a_1	0.443	0.289	0.305	0.600	0.241	0.281
110 (" ")	a_o	-15.346	0.373	1.429	-16.413	4.012	-3.600
110 (" ")	A_1	0.583	0.311	0.218	0.750	0.250	0.396
110 (" ")	A_o	-15.000	-0.500	3.75	-15.125	4.000	-3.980

Table 111

Summarizes the analysis of variance used to test the significance of the stimulus intensity and stimulus duration differences in TTS shown in figure 8.

(a) Intensities less than 95 db.

Source of Variance	Sum of Squares	Degrees of freedom	Variance Estimate	F ratio
Stimulus Intensity	6.62	5	1.32	3.77
Stimulus Duration	94.45	2	47.23	134.90 a
Residual	3.55	10	0.35	-
Total	105.62	17		

(b) Intensities greater than 95 db.

Source of Variance	Sum of Squares	Degrees of freedom	Variance Estimate	F ratio
Stimulus Intensity	239.16	5	47.83	11.66 a
Stimulus duration	374.33	2	187.16	45.64 a
Residual	41.02	10	4.10	-
Total	654.51	17		

a Probability less than 0.01

Table IV

Increase in Temporary Threshold Shift in db. at the given stimulus intensities and durations, above the Temporary Threshold Shift at a stimulus intensity of 95 db. For calculation of significance see text and table V

Stimulus Intensity in db.	Duration.		
	1 min.	2 mins.	3 mins.
100	0.2	-0.2	3.6
105	1.2	3.6	7.1 a
110	3.2	3.8 b	5.7 a
115	4.0 b	6.8 a	14.2 a
120	6.6 a	9.6 a	15.8 a
Mean	3.04	4.72	9.28

a Probability less than 0.01

b Probability less than 0.05

It was decided to statistically test the validity of the above statements by subjecting the data to an analysis of variance. The selection of this method was made after a consideration of the population from which the sample was drawn, the manner in which the sample scores were obtained and the level of measurement employed. The population from which the scores were obtained was considered to have a normal distribution of TTS. Glorig, Summerfield and Ward (1958) have shown with a sample of 99 normal hearing subjects that the distribution of TTS is normal. The sample scores used in this experiment were drawn from a population of normal hearing subjects (see Appendix lV) and we can assume that their distribution of TTS would be similar to that of the population from which they were drawn. All scores within any given experimental condition were independent. Finally the scale of measurement used was an interval scale, since it has an arbitary zero of zero TTS. The above statements show that the data fulfills all the pre-requisits which allow a simple analysis of variance technique to be utilized (see Lindquist, 1953, pages 51 to 52).

Since it was postulated that intensity differences at stimulus intensities less than 95 db. were not significant and differences at stimulus intensities greater than 95 db. were significant, it was necessary to sub-divide the data on this basis. Hence, the analysis was applied seperately to stimulus intensities less than and including 95 db. and stimulus intensities greater than and including 95 db. Two tables were drawn up with the six stimulus intensities shown as columns and the three stimulus durations shown as rows. These were the tables analysed. The results of the analysis are summarized in table 111. It can be seen from the table that intensity differences below 95 db. are not significant and intensity differences above 95 db. are significant.

A further analysis of the data was carried out by calculating the differences between TTS at 95 db. and TTS at higher intensities. These results are summarized in table lV. The differences of 0.2

Table V

Summary of t - test applied to data of table IV using the data calculated in table III

From table III, residual degrees of freedom = 10

From table III, residual variance estimate (σ^2) = 4.10.

t for 10 degrees of freedom = 2.23 and 3.17
at 5% and 1% level respectively.

$$\text{Standard deviation} = \sqrt{\sigma^2} = 2.03$$

$$\text{Standard error of mean } (\sigma_d) = \sigma\sqrt{\frac{1}{N_1} + \frac{1}{N_2}}$$

$$= 2.03\sqrt{\frac{1}{3} + \frac{1}{3}}$$

$$= 1.65$$

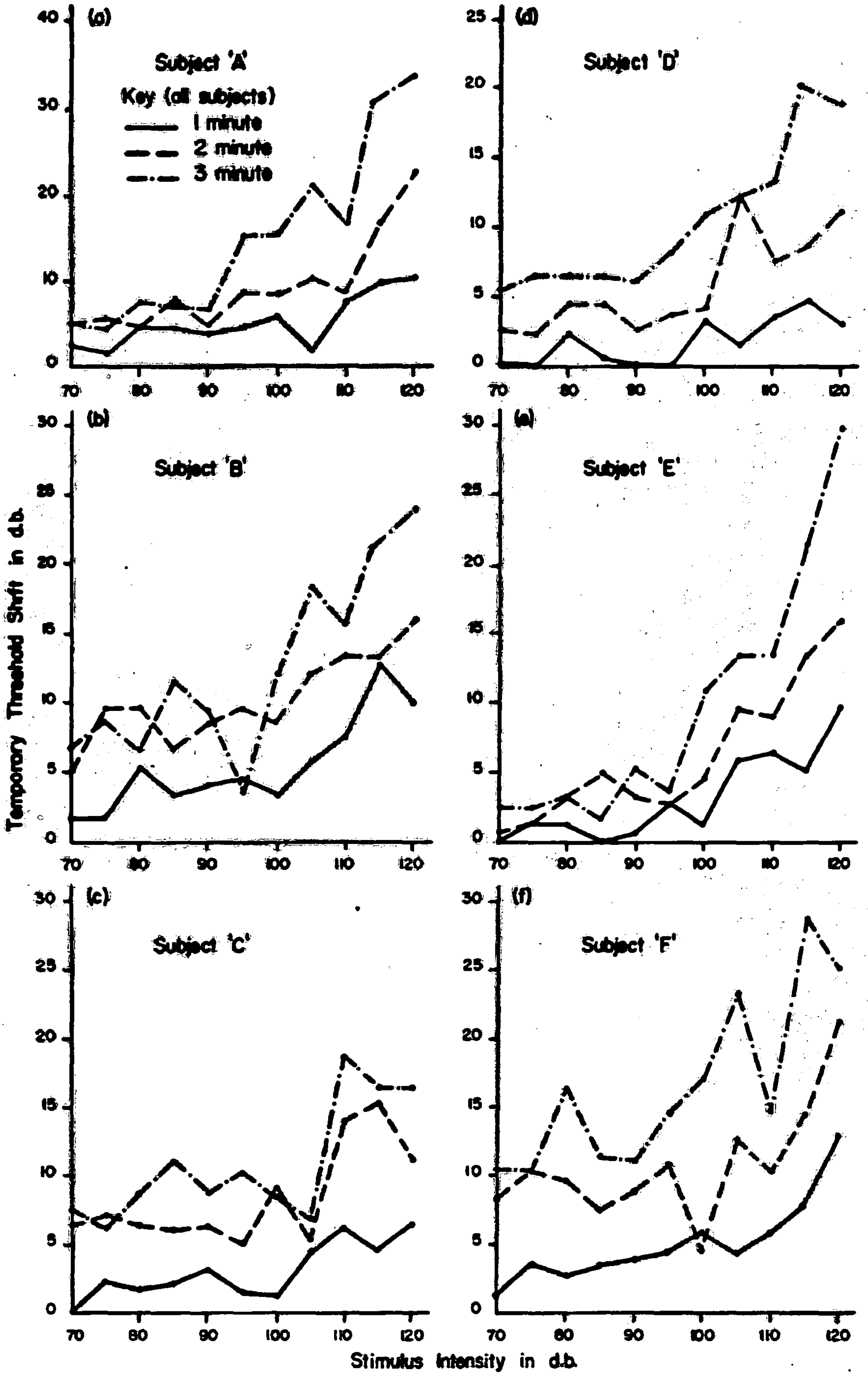
$$t = \frac{M_1 - M_2 - 0}{\sigma_d}$$ (see Garrett, 1955, p.223)

$$\therefore M_1 - M_2 = 2.23 \times 1.65$$

$= \underline{3.67}$ for significance at 0.05 level

$$\text{and } M_1 - M_2 = 3.17 \times 1.65$$

$= \underline{5.23}$ for significance at 0.01 level.



Figures 8a and 8f : Show the individual results obtained for TTS as a function of the stimulus intensity. Parameter is stimulus duration.

and -0.2 db. at a stimulus intensity of 110 db. and at stimulus durations of 1 and 2 minutes respectively, and the difference of 1.2 db. at a stimulus intensity of 105 db. and at a stimulus duration of 1 minute are probably not significant. If this is the case then the table indicates that as the stimulus duration is increased there is an increase in the stimulus intensity at which increases in TTS occur. To test this suggestion the data calculated in the analysis of variance summarized in table 111 was used. Using $F = \sqrt{t}$ the differences shown in table 1V were tested for significance, using the technique outlined by Garrett (1955, page 280). The calculations are summarized in table V. It can be seen from table V that the following differences are not significant:

(i) Those of 0.2, 1.2 and 3.2 db. at a stimulus duration of 1 minute.

(ii) These of 0.2 and 3.6 db. at a stimulus duration of 2 minutes.

(iii) That of 3.6 db. at a stimulus duration of 3 minutes.

Hence the observation is confirmed.

Inspection of figure 8 indicates that there is divergence of the 1, 2 and 3 minute lines as the stimulus intensity is increased. This divergence is to some extent masked by the drop in TTS at 110 db. with a stimulus duration of 3 minutes. However, inspection of table 1V indicates that at 110 db., the increase in TTS above the 95 db. level is larger at 3 minutes (5.7 db.) than at either 1 or 2 minutes (3.2 and 3.8 db. respectively). Thus the table indicates that as the stimulus intensity is increased above 95 db. the increases in TTS are greater at 3 minutes than at 2 minutes and at 2 minutes than at 1 minute and that as the stimulus intensity is increased, these differences also increase in magnitude.

The agreement between the individual and the mean results are indicated by figures 8 a to 8 f which present the data for individual subjects. As in Condition 'A' allowing for the greater variation of

Table VI

Summarizes the analysis of variance used to test the significance of the stimulus frequency differences shown in figures 9, 10 and 11. The ten stimulus frequencies were plotted as rows and the nine stimulus duration - stimulus intensity conditions were plotted as rows.

Source of Variance	Sums of Squares	Degrees of freedom	Variance Estimate	F ratio.
Stimulus frequency	388.12	9	43.12	38.84 a
Conditions	274.47	8	34.43	31.02 a
Residual	80.19	72	1.11	-
Total	742.78	89		

a Significant at 0.01 level.

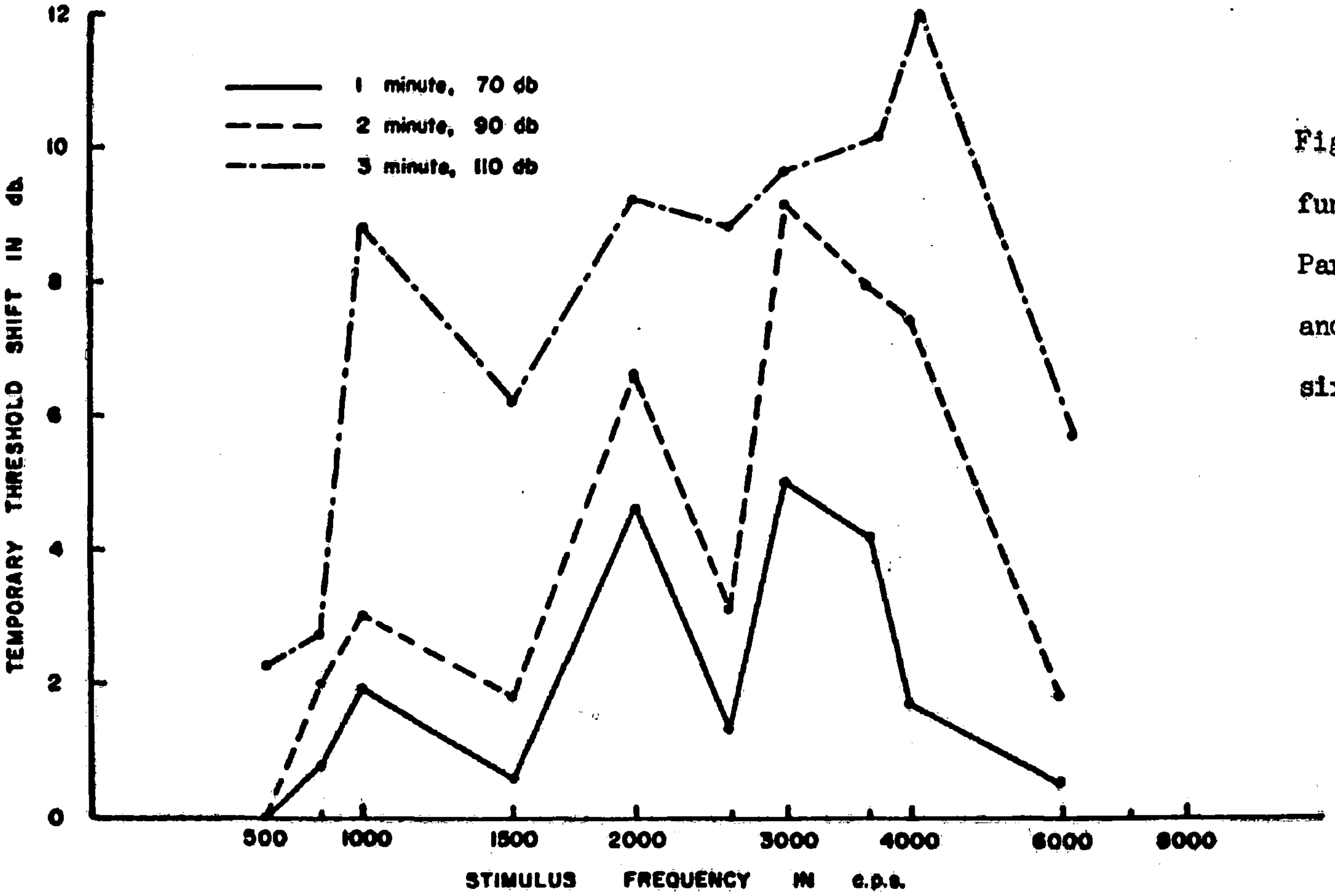


Figure 9: Graph of TTS as a function of stimulus frequency. Parameters are stimulus duration and intensity. Mean results for six subjects.

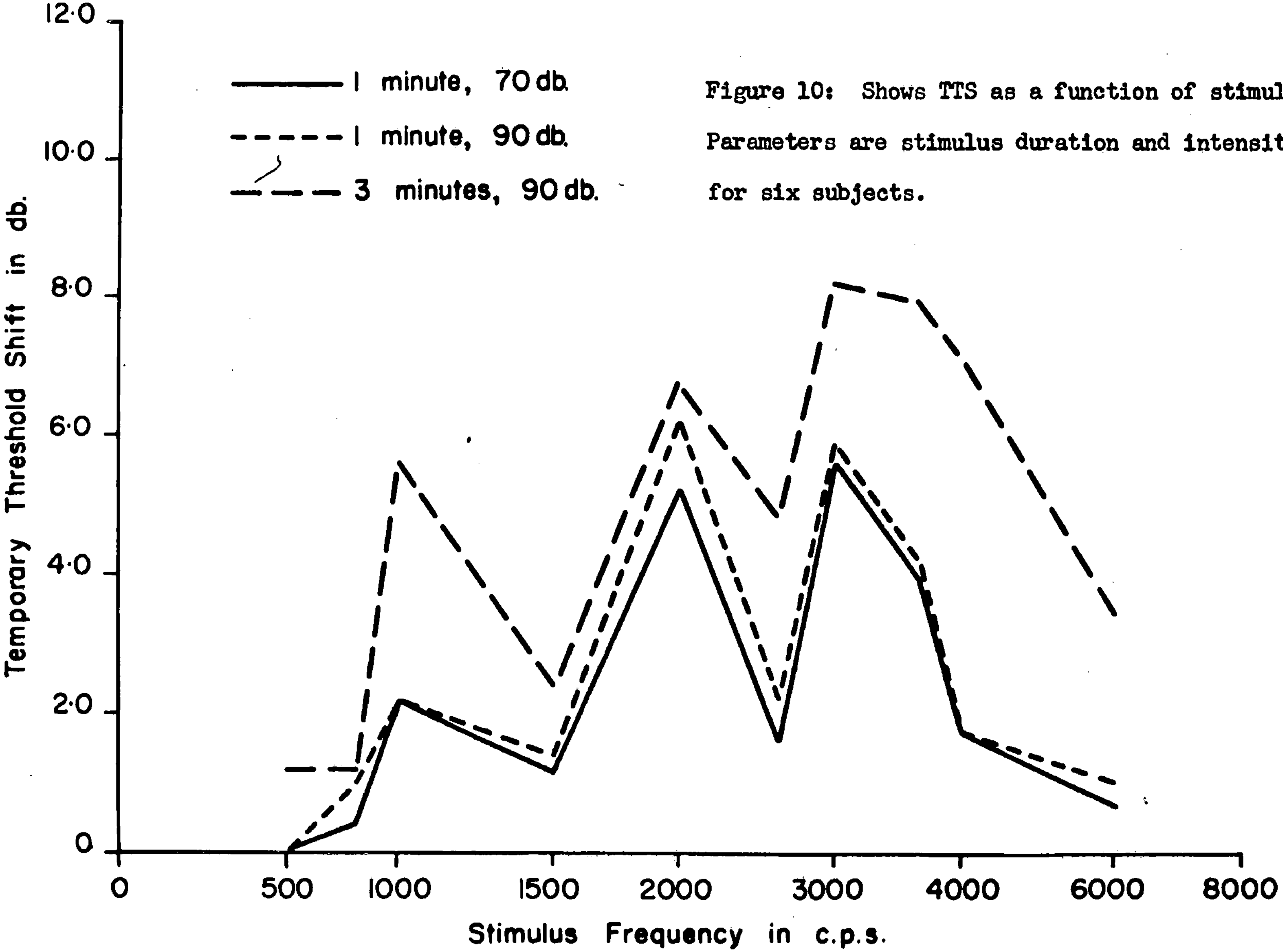


Figure 10: Shows TTS as a function of stimulus frequency. Parameters are stimulus duration and intensity. Mean results for six subjects.

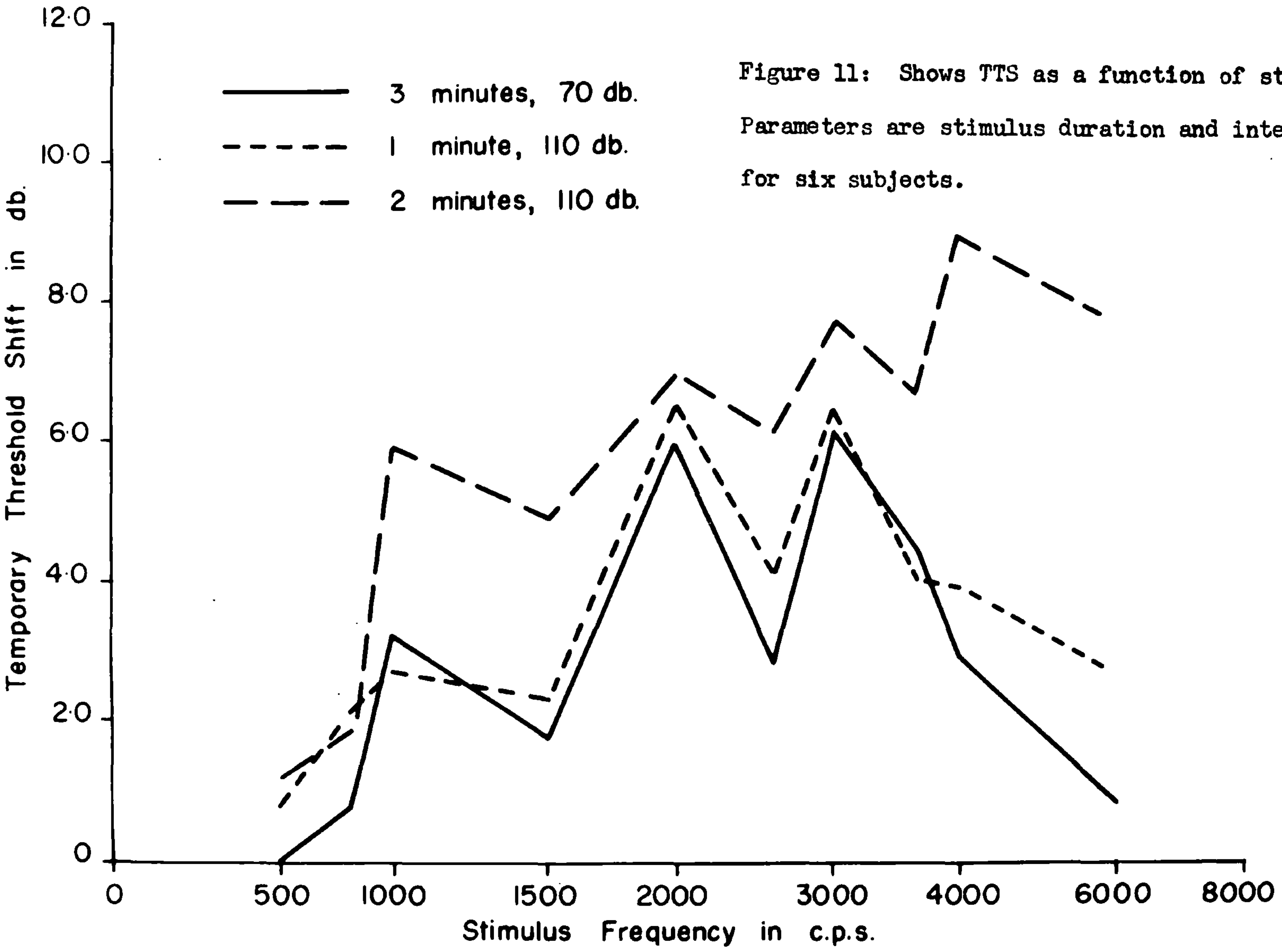


Figure 11: Shows TTS as a function of stimulus frequency. Parameters are stimulus duration and intensity. Mean results for six subjects.

individual results there is close agreement between the individual and the mean results except in the case of subject 'C'. In the case of the latter, the 1, 2 and 3 minute lines tend to remain very close together and there are only slight increases in TTS as the stimulus intensity is raised above 9 db. There is some individual variation in the stimulus intensity at which increases in TTS begin to occur. For the individual subjects this occured over the range 85-100 db.

(c) Condition 'C': As in Conditions 'A' and 'B' mean results were calculated for the group of six subjects used in this condition. The mean results are illustrated in figures 9, 10 and 11. The subdivision of the results into three figures is merely for clarity of presentation. The figures indicate that with stimulus durations of 1, 2 and 3 minutes at stimulus intensities of 70 db. and 90 db., TTS is maximal at stimulus frequencies of 1000, 2000 and 3000 cps. Similarly, with a stimulus duration of 1 minute at a stimulus intensity of 110 db., TTS is maximal at 1000, 2000 and 3000 cps. However, with stimulus durations of 2 and 3 minutes at a stimulus intensity of 110 db., TTS appears to be maximal at 1000, 2000 and 4000 cps. In the latter case it is also possible that a further maximum might have occured at 3000 cps; but there are insufficient data to determine whether this is so.

To determine whether the frequency differences were significant the data was analysed using analysis of variance. The justification for using this technique has already been presented (see page 76). In the analysis, stimulus conditions were plotted as the rows and stimulus frequencies were plotted as the columns. The results of the analysis are summarized in table VI. It can be seen from this table that the frequency differences in TTS are significant at the 0.01 level. Hence the above observations are justified.

The results for all of the individual subjects are not shown. However, figure 12 shows the results for subject 'H'. This subject was the most typical of the subjects. The individual results confirmed the above statements except for four exceptions. Two of the subjects,

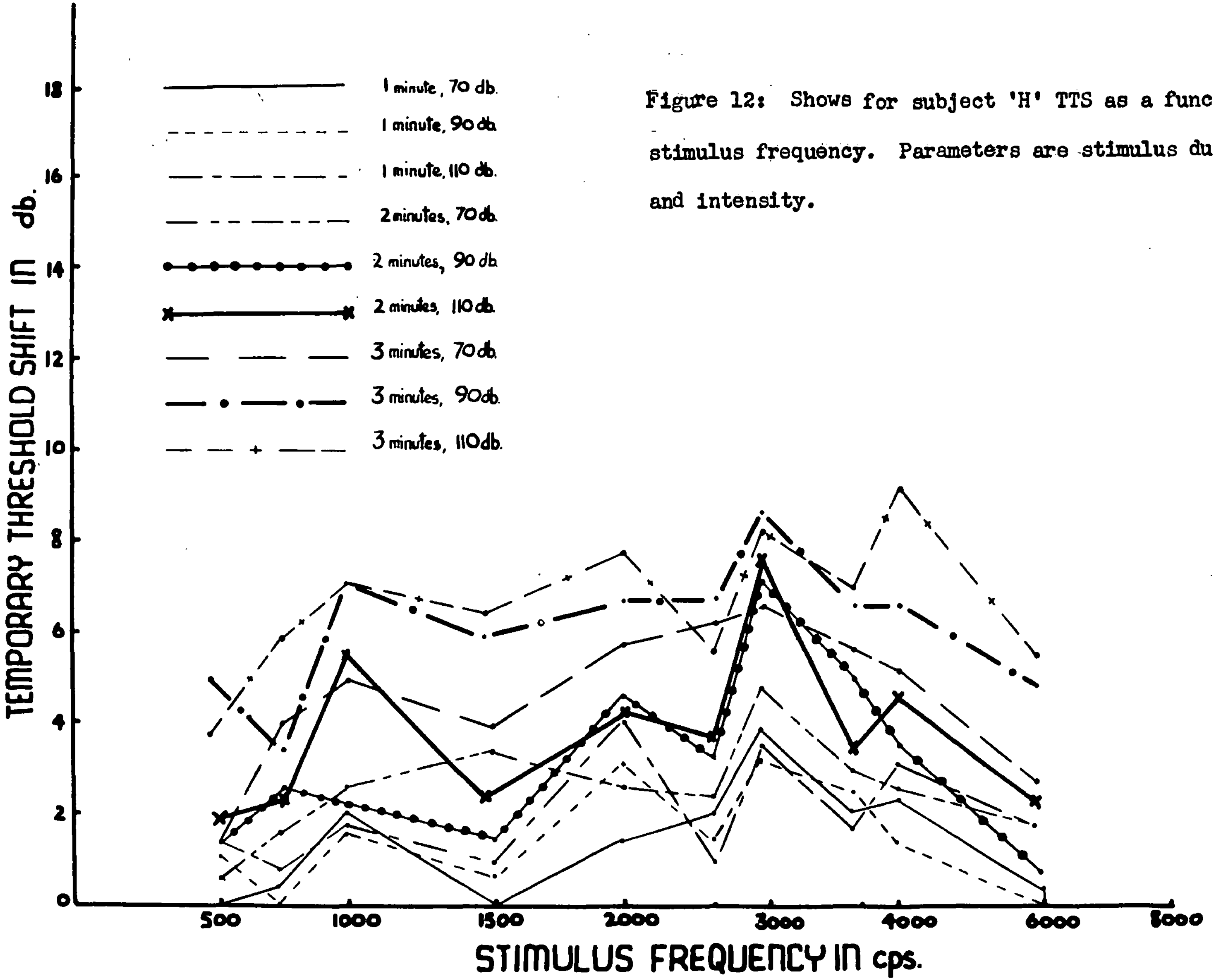


Figure 12: Shows for subject 'H' TTS as a function of stimulus frequency. Parameters are stimulus duration and intensity.

with stimulus intensities of 110 db. and with stimulus durations of three minutes, gave maximal TTS at 1000, 2000 and 6000 cps and not at 1000, 2000 and 4000 cps. This tends in figures 9 and 10 to elevate the 6000 cps point and lower the 4000 cps point on the lines with these parameters. Another two of the subjects, with stimulus intensities of 110 db. and a stimulus duration of two minutes, gave results which were qualitatively similar to the line shown in figure 9 with a stimulus duration of three minutes at a stimulus intensity of 110 db.

(d) Test Tone Variables : Pre-stimulus and post-stimulus tone thresholds were calculated, as in the previous experiments, by taking the mean of the transition points in the pre-exposure and post-exposure periods. The mean TTS for the six subjects in each of the five stimulus conditions and at each test frequency were calculated.

The results are summarized in figures 13a to 13e. It can be seen from these figures that for all but two stimulus conditions, maximal TTS occurs at a test frequency half an octave above the stimulus tone. One exception is a stimulus tone of 2000 cps at a stimulus intensity of 70 db. and a stimulus duration of 3 minutes. The other exception is a stimulus tone of 6000 cps at a stimulus intensity of 70 db. and at a stimulus duration of 3 minutes. With the former condition, TTS is maximal at 4000 cps and with the latter condition, TTS is maximal at 6000 cps. The figures also reveal that the effect of increasing the severity of the stimulus conditions produces its greatest effect at the test frequency at which maximal TTS occurs. Increased severity of the stimulus conditions seems to affect the amount of TTS in proportion to the amount by which the test tone frequency deviates from the test frequency at which maximal TTS occurs; hence the "bowing" of the curves. The distribution of TTS over the various test tone conditions is positively skewed, except with a 1000 cps stimulus. The frequencies below the test tone frequency at which maximal TTS occurs are much less affected than those above this frequency. The results obtained confirm that with high stimulus intensities and fairly long stimulus durations, there is a proportionally larger increase in TTS. A stimulus duration of 3 minutes at a stimulus intensity of 110 db.

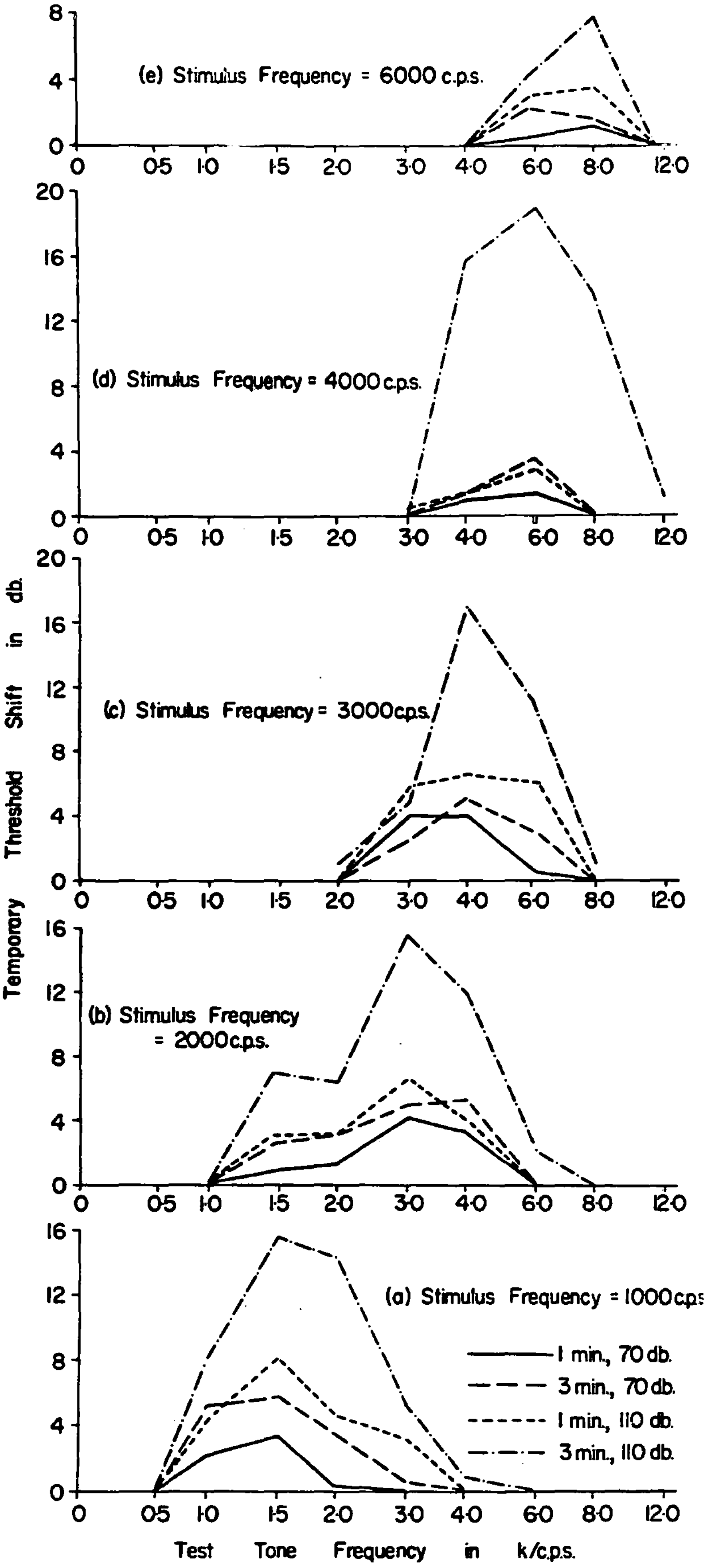


Figure 13 : Shows TTS as a function of test tone frequency. Mean results for six subjects. Parameters are stimulus duration and stimulus intensity.

Table Vll

Summary of the analysis of variance to test the significance of differences in TTS with the test tone frequency and with the 4 stimulus conditions. Data used is presented in figure 13.

Stimulus Tone in cps.	Source of Variance	Sum of Squares	Degrees of Freedom	Variance estimate	F Ratio
1000	Test tones	180.26	4	45.06	3.56 b
	Stimulus Conditions	38.69	3	12.90	1.02
	Residual	151.74	12	12.64	-
	Total	370.69	19	-	-
2000	Test tones	100.51	4	25.13	11.85 a
	Stimulus Conditions	154.89	3	51.63	24.35 a
	Residual	25.39	12	2.12	-
	Total	279.79	19	-	-
3000	Test tones	180.81	4	45.20	6.80 a
	Stimulus Conditions	86.80	3	28.93	4.35 b
	Residual	79.75	12	6.65	-
	Total	356.36	19	-	-
4000	Test tones	130.07	4	32.52	5.15 b
	Stimulus Conditions	393.31	3	131.10	20.78 a
	Residual	75.67	12	6.31	-
	Total	599.05	19	-	-
6000	Test tones	2.53	1	2.53	1.74
	Stimulus Conditions	28.27	3	9.42	6.50
	Residual	4.36	3	1.45	-
	Total	35.16	7	-	-

a Probability less than 0.01

b Probability less than 0.05

Table VIII

Shows in the body of the table the range (in octaves) of test frequencies affected by the indicated stimulus tones and at the indicated stimulus intensities and durations.

		Stimulus Frequency				
Stimulus Duration in minutes	Stimulus Intensity in db.	1000	2000	3000	4000	6000
1	70	1	1½	1½	½	½
3	70	1½	1½	1½	½	½
1	110	1½	1½	1½	1½	½
3	110	2	2	2	1½	½

affects all test frequencies much more than any of the other conditions. Suprisingly, at a stimulus frequency of 4000 cps, TTS is greater with a stimulus intensity of 70 db. and a stimulus duration of 3 minutes than with a stimulus intensity of 110 db. and a stimulus duration of 1 minute. At all other stimulus frequencies the reverse is found.

To test the significance of the test-tone frequency differences and stimulus condition differences, the data was subjected to an analysis of variance (see McNemar, 1962, pages 290 to 296). The justification for using this technique has been outlined on page 76. Each stimulus frequency was treated separately and the results are summarized in table Vll. It can be seen from this table that only at a stimulus frequency of 6000 cps are the differences in TTS with test frequency not significant. The table also reveals that only at 1000 and 6000 cps are the differences between the stimulus conditions not significant. These non-significant differences are probably due to the fact that differences in TTS are relatively very small between the different conditions. Since seven out of ten of the differences are significant, it would appear that the general conclusions reached above are correct. However, it may be that these conclusions do not hold for stimulus frequencies of 1000 and 6000 cps.

Further information was obtained from figure 13 by considering the range of test frequencies affected at each stimulus frequency and under each of the stimulus conditions. These ranges are summarized in table Vlll. It can be seen from the table that there is an increase in the range of octaves affected as the severity of the stimulus exposure is increased. It can also be seen that there is a decrease in the range of octaves affected as the stimulus frequency is raised from 3000 to 6000 cps. However, the range is relatively constant with stimulus frequencies of less than 3000 cps.

The individual results were again very similar to the mean results. Allowing for chance variations, five out of the six subjects consistently showed maximal TTS at a test frequency a half an octave above the stimulus frequency. The sixth subject (see figure 14) showed a tendency

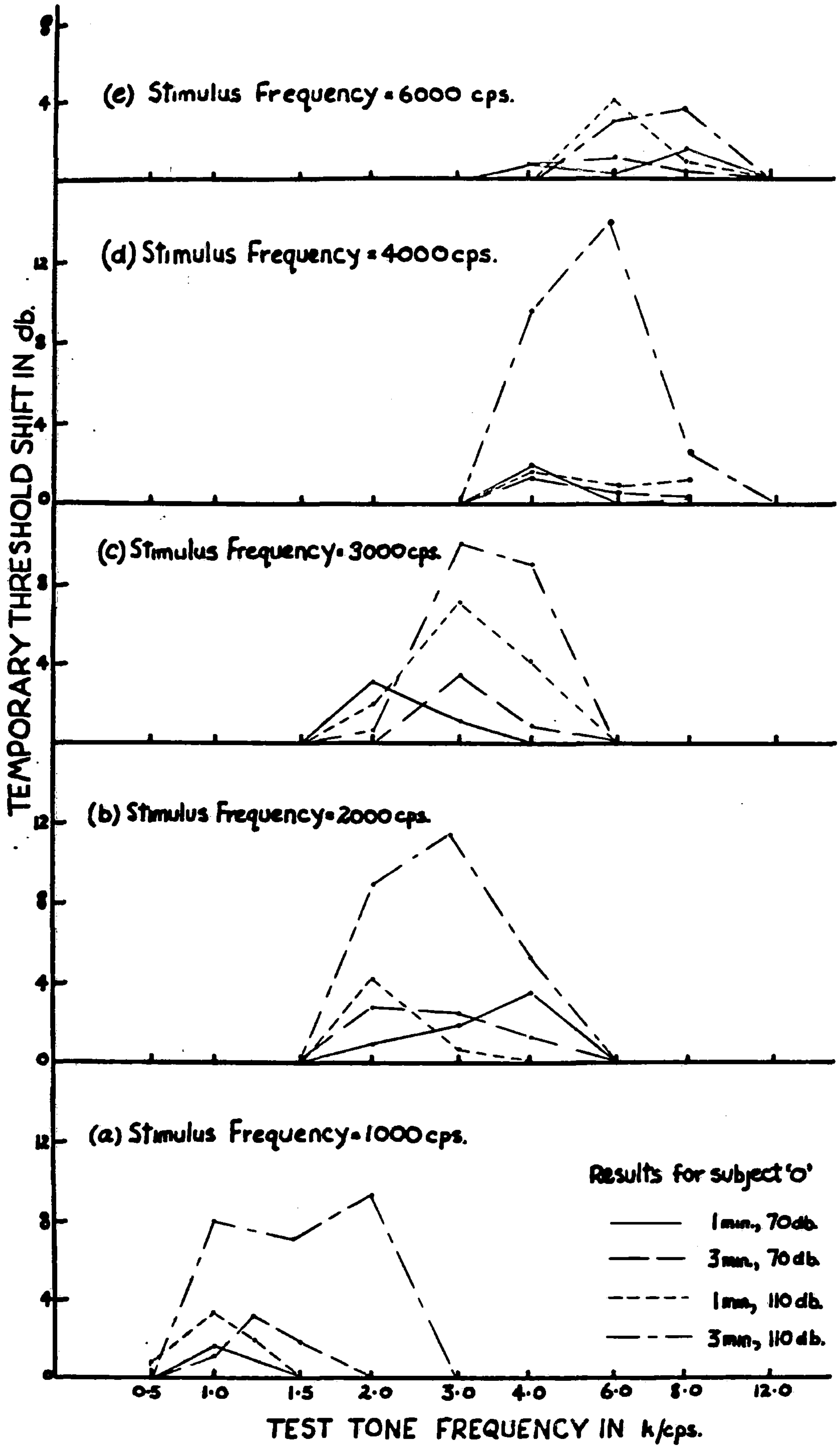


Figure 14: Results for subject 'O' showing TTS as a function of test tone frequency. Parameters are stimulus duration and intensity.

for maximal TTS to occur at a test frequency equal to the stimulus frequency. This was not generalized, but it occured sufficiently to destroy the typical pattern associated with the other individual results and the mean results.

CHAPTER 1X

RECOVERY FROM TTS.

Two experiments were carried out on recovery from TTS (see pages 57 to 59). These were :

(i) An experiment studying the time taken for the threshold to recover to normality (latent time).

(ii) A study of the material collected during the experiments on the stimulus and test tone variables.

The results obtained are given below.

(a) Recovery Time

The mean latent time for recovery was calculated for the four subjects used in the experiment at each stimulus frequency and intensity. The stimulus duration was one minute throughout the course of the experiments. The results are illustrated in figure 15. In this figure the stimulus intensity is plotted in terms of db. re 0.0002 dynes per cm^2 rather than in terms of db. re the subjects threshold. This equates the physical intensities for the different subjects. Since individual thresholds vary, the points shown on the abscissa in figure 15 cover a small range of intensities. For a stimulus / test frequency of 1000 cps the range was 4 db., for 2000 cps the range was 2 db., for 4000 cps the range was 7 db. and for 8000 cps the range was 3 db. However, since there is no overlap in the ranges covered, the only effect this would have on the results is to widen the individual differences. It would not affect the shape of the graphs or the general conclusions that can be drawn from the results since for each subject successive intensity differences are always 10 db.

Inspection of figure 15 gives rise to the following observations :

(i) At 1000 and 2000 cps there is a gradual increase in mean latent times as the stimulus intensity is increased from 20 db. to approximately 60 db. From approximately 60 to 80 db. the mean latent times decrease and above 80 db.

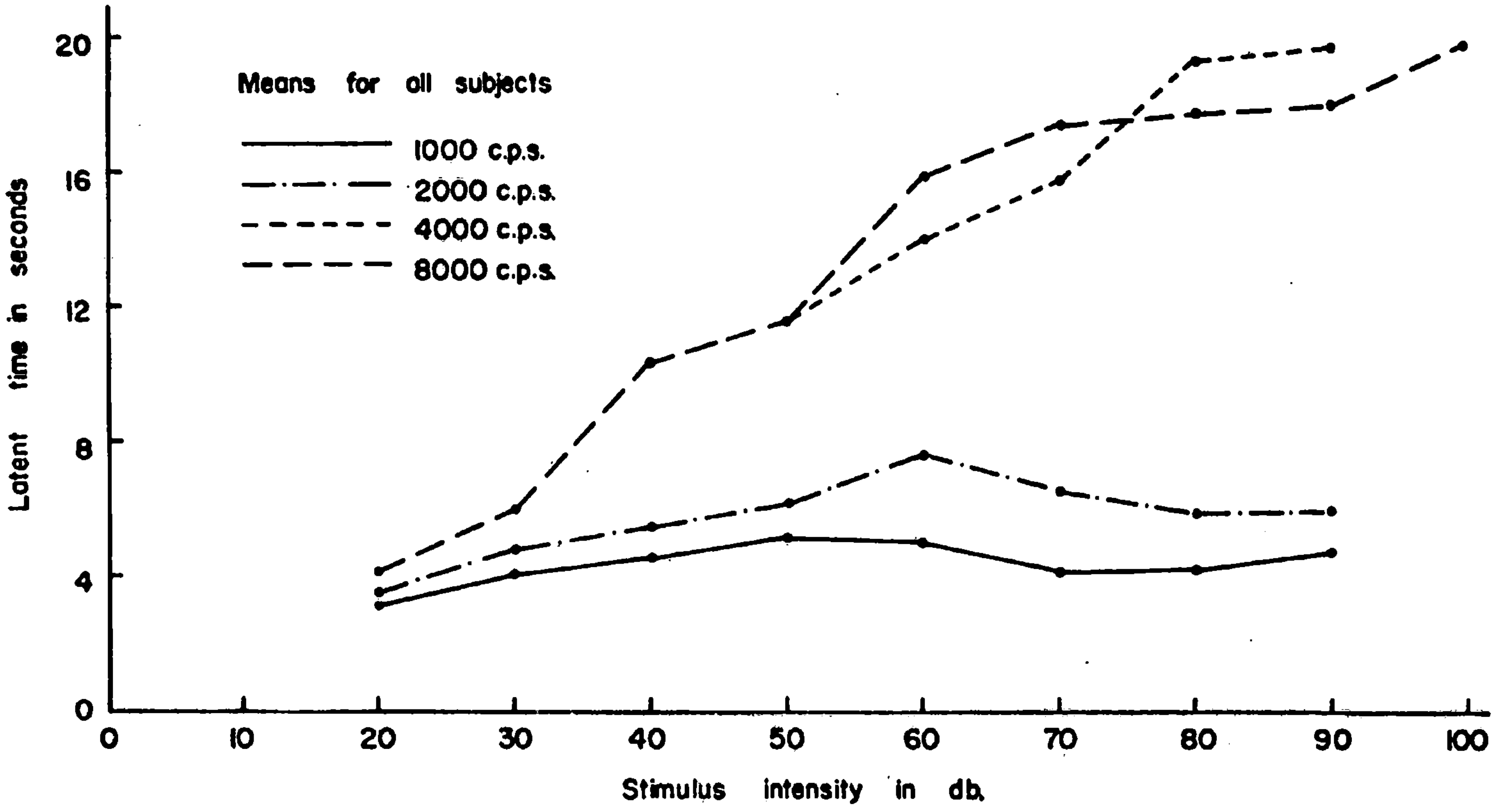


Figure 15: Graph of latent time as a function of stimulus intensity. Parameter is stimulus/test frequency. Mean results for four subjects.

Table IX

Analysis of Variance of intensity and replication relationships in recovery from TTS. Data from 4 subjects.

	Intensity			Replications			Error	
Frequency in cps	Variance Estimate	Degrees of Freedom	F Ratio	Variance Estimate	Degrees of Freedom	F Ratio	Variance Estimate	Degrees of Freedom
1000	1.328	7	27.669 a	0.185	2	3.854	0.048	14
2000	4.274	7	57.756 a	0.055	2	0.743	0.074	14
4000	94.128	8	290.518 a	0.620	2	1.914	0.324	16
8000	51.952	4	125.185 a	0.640	2	1.542	0.415	8

a Probability less than 0.01

there appear to be slight increases in the mean latent times.

(ii) At 4000 and 8000 cps, there is a gradual negatively accelerating increase in latent time as the stimulus intensity is increased.

(iii) The latent time is maximal at 4000 or 8000 cps and is minimal at 1000 cps.

The significance of these observations was tested statistically by means of analysis of Variance and a 't' - test. To do this the original measurements used in calculating the results for the individual subjects were utilized. The analysis follows that described by Lindquist (1953, pages 190-202) for "The Special Case of Simple Replications." Mean latent times for the four subjects were calculated for the first, second and third replications at each intensity. A table was drawn up plotting intensities as columns and replications as rows. Mean latent times were inserted into the body of the table and the table subjected to analysis of variance. The advantage of this method of analysis is that it removes group differences from the error variance. Hence only interaction effects remain in the latter (see Lindquist, op cit.,page 201). The justification for using the technique is that the replications and the treatments were randomized, the cells in the analysis each contained the same number of cases and replication differences were reduced because of the previous training. This fulfills the main criteria governing the use of this type of analysis (see Lindquist, op cit., page 199 to 200).

The procedure was repeated at each stimulus/test frequency. The results of the analysis are summarized in table 1X. It can be seen from the table that at each of the four frequencies used in the experiment, the mean latent time varies significantly with stimulus intensity at the 0.01 level of confidence. The table also indicates that the differences in latent time for the different replications are not significant. Since the subjects were given considerable practice prior to the experiment, this is to be expected.

Table X

Results of t-test to determine number of differences significant in figure 15. (See Garrett, 1958, page 281).

Data used is presented in table 1X.

Frequency in cps	Difference required for significance at 0.05 level of confidence	Difference required for significance at 0.01 level of confidence	Number of possible Differences	Number of differences significant at 0.05 level	Number of differences significant at 0.01 level	Number of differences not significant
1000	0.383	0.533	28	6	17	5
2000	0.475	0.661	28	3	23	2
4000	0.980	1.356	36	1	32	3
8000	0.385	0.559	10	0	10	0

Table XI

Results of t-test to determine which of the differences (shown in body of table) between successive stimulus intensities are significant. The differences are measured in db. and the significance figures are given in table X.

Frequency in cps.	Difference between:							
	20-30 db	30-40 db	40-50 db	50-60 db	60-70 db	70-80 db	80-90 db	90-100 db
1000	0.90 a	-0.67 a	0.60 a	-0.17	-0.83 a	-0.07	0.50 a	-
2000	1.18 a	0.48 b	1.16 a	1.37 a	-1.00 a	-1.18 a	0.00	-
4000	1.87 a	4.16 a	1.36 b	4.19 a	1.46 a	0.47	0.29	1.40 a
8000	-	-	-	1.78 a	2.45 a	3.39 a	2.37 a	-

a Significant at 1% level of confidence

b Significant at 5% level of confidence

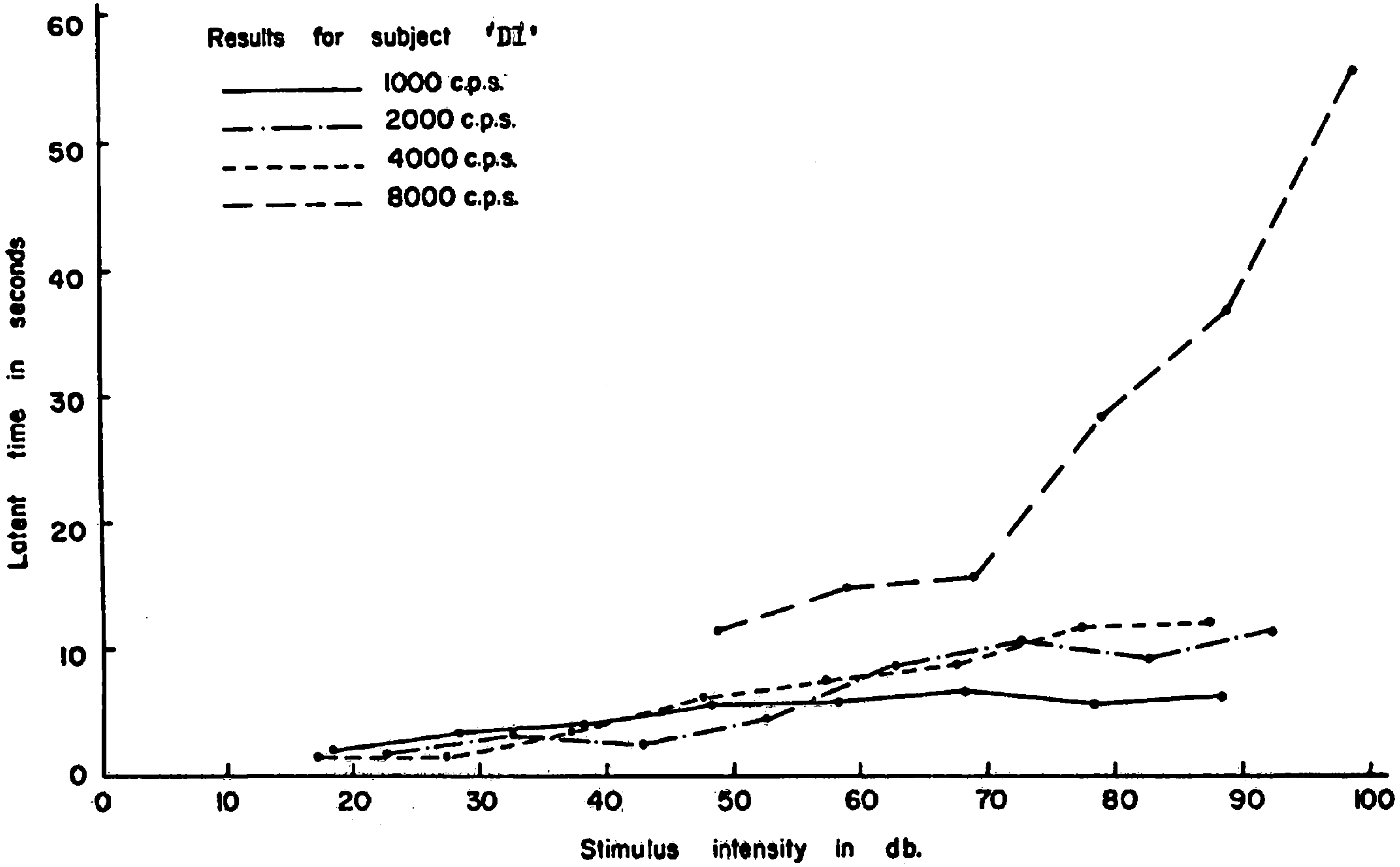


Figure 16: Results for subject 'D1' showing latent time as a function of stimulus intensity. Parameter is stimulus/test frequency.

Additional evidence for the relationships revealed in figure 15 was obtained by applying a 't' - test to the data used in the analysis of variance. The same method was used as was used to treat the data on the relationship between stimulus intensity and TTS (see page 78 and Garrett, 1958, page 281). The results of this test are summarized in table X. Inspection of the table reveals that at 1000 cps, only 5 out of 28 possible differences in latent time were not significant; at 2000 cps, only 2 out of 28 possible differences in latent time were not significant; at 4000 cps, only 3 out of 32 possible differences in latent time were not significant, and at 8000 cps all of the differences were significant. Hence we can conclude that the intensity differences revealed in figure 15 are significant.

However, there are 5 non-significant differences at 1000 cps and 3 at 2000 cps. It is important with reference to the peaks in the figure with these frequencies, to consider where these non-significant differences occur. Hence in table XI is presented the differences between successive means, that is between stimulus intensities of 20 and 30 db., 30 and 40 db. and so on. It can be seen from the table that the reduction in latent time between 60 and 70 db. at both 1000 and 2000 cps is significant at the 1% level, the reduction between 70 and 80 db. at 2000 cps is significant at the 1% level and the difference between 80 and 90 db. at 1000 cps is significant at the 1% level. At 4000 cps, all the differences except 2 are significant and at 8000 cps all the differences are significant. Hence, observations (i) and (ii) made above after inspection of figure 15 (see page 16) seem to be reasonably justified. The third observation must remain subjective. The 4 stimulus/test frequencies used in the experiment are insufficient to apply statistical tests because of the way in which the data was collected.

In figure 15 there does seem to be some confusion of the results since the 4000 and 8000 cps lines cross each other. However, this confusion was thought to arise from the results of one subject, subject 'Dl'. The individual results for this subject are presented in figure 16.

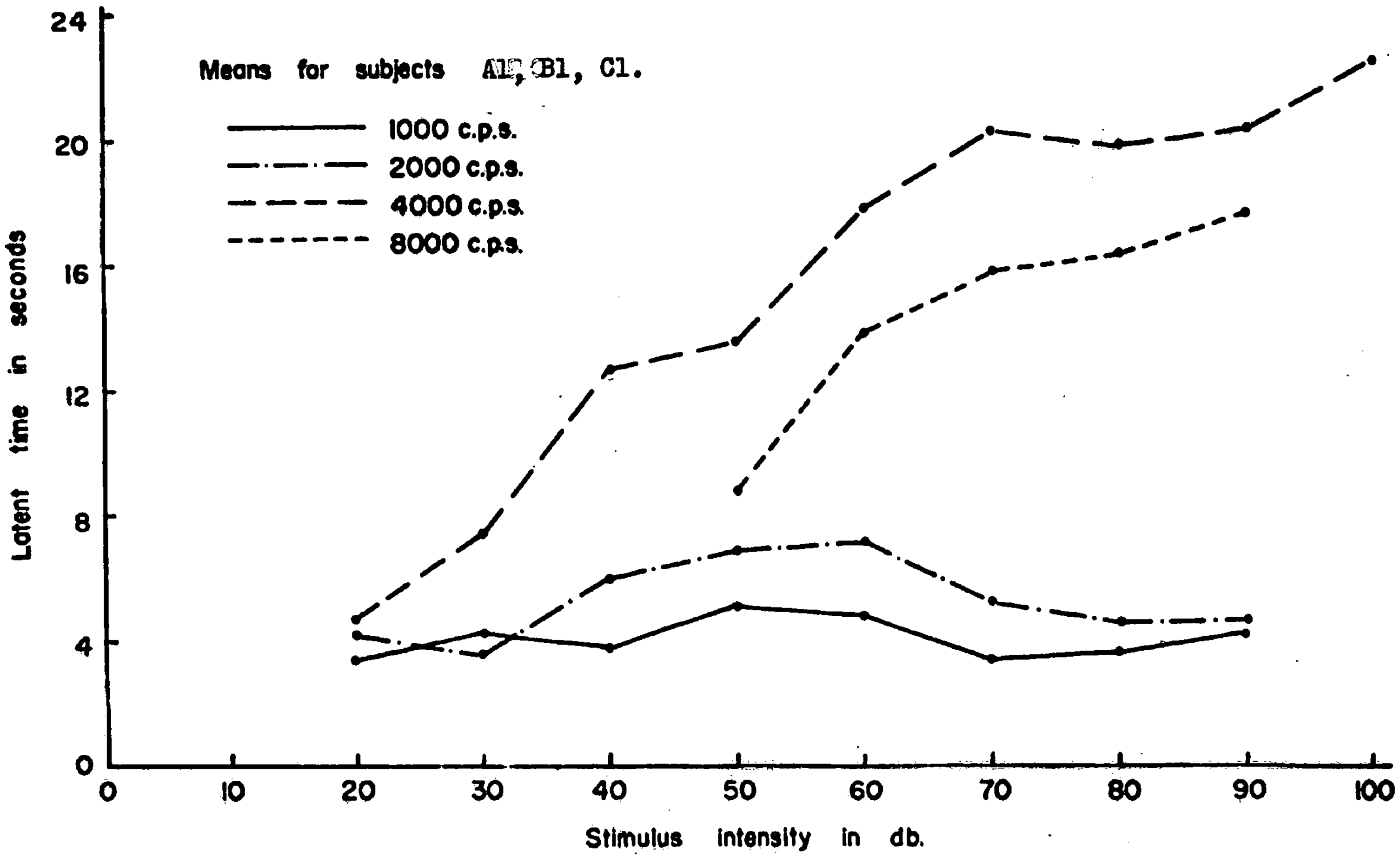


Figure 17: Mean results for subjects 'A1', 'B1' and 'C1' showing latent time as a function of stimulus intensity. Parameter is stimulus/test frequency.

Inspection of the figure reveals that the subject showed only small increases in latent time as the stimulus intensity was increased at 4000 cps, but very large increases at 8000 cps. When the mean results for the other three subjects are considered, it can be seen in figure 17 that there is no crossing of the 4000 and 8000 cps lines. Instead they tend to remain parallel to each other. The divergent results for this subject might be associated with the fact that for this subject hearing above 12000 cps was virtually non-existent. The subject complained of tinnitus when stimulated at 8000 cps and this may have been the cause of his abnormal behaviour at this frequency.

To summarize the results, we can say that :

(i) Latent time exhibits a "bounce" phenomenon at 1000 and 2000 cps, but not at 4000 and 8000 cps.

(ii) Latent time is maximal at 4000 cps and is minimal at 1000 cps.

(iii) The increases in latent time with intensity at 4000 and 8000 cps tend to parallel each other.

(iv) Judging from the results of subject 'DL', there may be large increases in latent time as the stimulus intensity is increased at stimulus frequencies just below the subjects' upper limit of hearing.

(b) Study of results obtained during the experiments on the stimulus and test tone variables.

Each of the 1950 individual results obtained on the studies of the stimulus and test tone variables were inspected and analysed to study the recovery from TTS. The three minute recovery period on each record was examined and a subjective judgement made as to whether or not recovery was diphasic, as to whether or not sensitization occured and as to whether or not, if bounce occured, it was higher than the initial TTS. The mean of the first two transition points in the post exposure period was calculated and this was taken as measure of initial TTS (see points A and B on figures 18a to 18c). If bounce occured, the mean of the three transition points at the initial return to threshold value (see points a, b and c on figures 18 a to 18 c) and the mean of the three transition

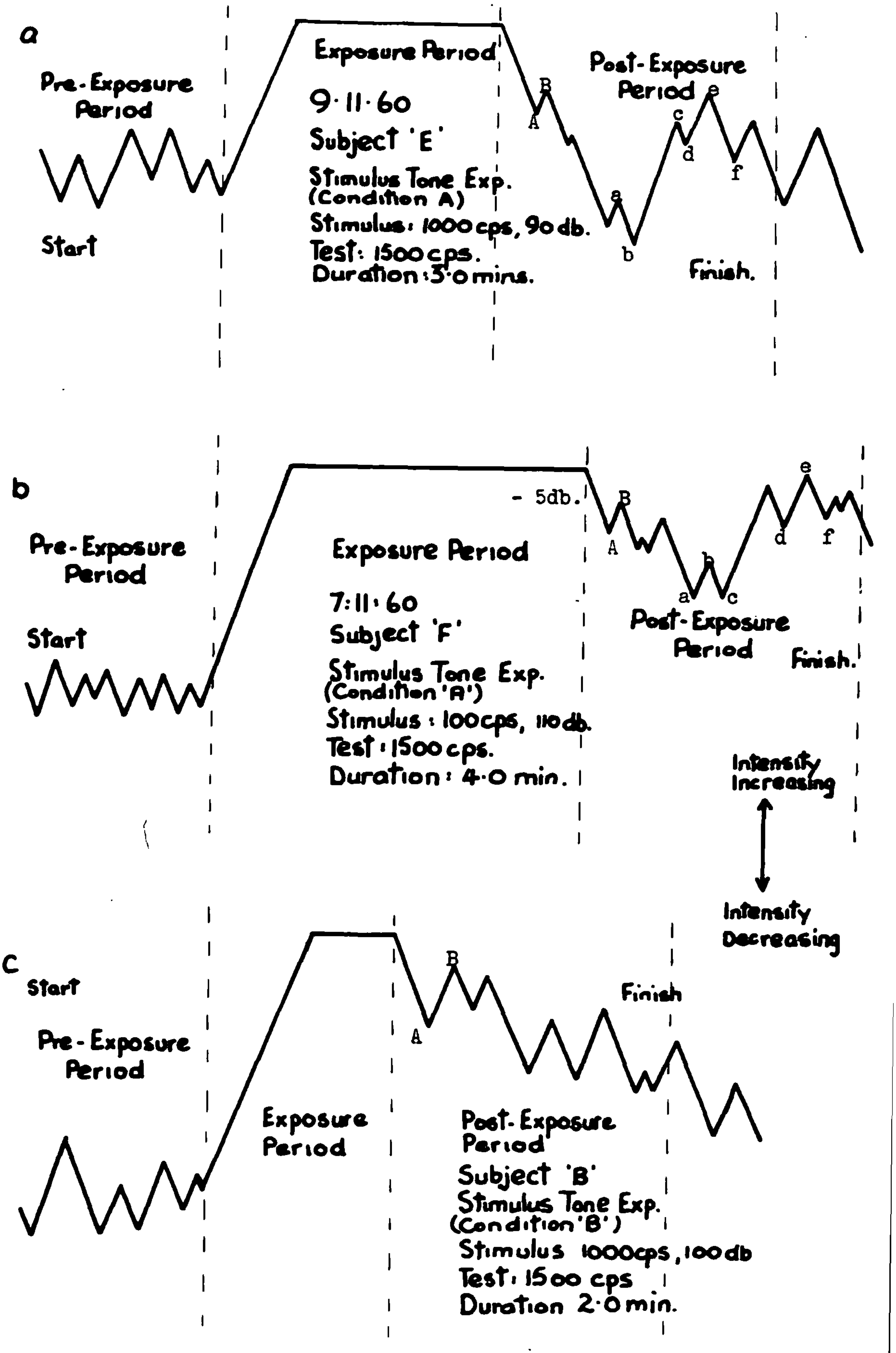


Figure 18: Typical tracings illustrating recovery from TTS (see table X11, page 98). Time reads from left to right (1" to 1.5 mins). Intensity reads from top to bottom (1" to 8.89 db.)

Table XII.

Summarizes the analysis of the three recovery curves shown in figure 18 (page 97).

Figure	Diphasic Recovery	Sensitization	Initial TTS.	Bounce higher than initial TTS.	Amount of bounce.
18a	Yes	Yes	3.72	No.	3.52
18b	Yes	No	15.55	Yes	11.11
18c	No.	No.	12.22	-	-

Table XIV

Summarizes the chi-squared analysis of the total frequency of judgements of the presence of diphasic recovery, sensitization and bounce higher than initial TTS in order to see if this differs significantly from chance.

	Chi - Square	Degrees of freedom	Probability
Diphasic Recovery	776.28	2	Less than 0.01
Sensitization	935.44	2	Less than 0.01
Bounce higher than initial TTS	139.00	2	Less than 0.01

Table XV

Shows in the body of the table the number of results classified as being diphasic, as showing sensitization and in which bounce was higher than the initial TTS.

Part 1.

Experiment. Stimulus tone Variables (Condition 'A')

Main Variable. Stimulus Intensity

	70 db.	90 db.	110 db.
Diphasic Recovery. Subjects			
A	8	11	7
B	7	10	3
C	9	13	12
D	9	5	2
E	1	3	0
F	3	10	5
Sensitization Subjects			
A	14	14	3
B	12	14	12
C	10	11	0
D	12	14	3
E	6	1	2
F	10	9	1
Bounce higher than initial TTS. Subjects			
A	0	8	7
B	1	6	3
C	0	1	3
D	2	0	2
E	1	3	0
F	1	1	0

Part 2.

Experiment. Stimulus tone variables (Condition 'B')

Main Variable. Stimulus Duration.

	1.0 min.	2.0 min.	3.0 min.
Diphasic Recovery Subjects			
A	11	5	2
B	6	11	3
C	11	3	9
D	8	11	4
E	11	9	6
F	10	2	0
Sensitization Subjects			
A	11	9	2
B	6	6	4
C	4	7	4
D	10	10	4
E	5	3	1
F	10	7	5
Bounce higher than initial TTS. Subjects			
A	6	5	0
B	1	6	3
C	9	3	2
D	1	3	2
E	1	4	2
F	4	10	1

Part 3.

Experiment Stimulus tone (Condition 'C'

Main Variable Stimulus Frequency (in cps.)

	500	750	1000	1500	2000	2500	3000	35	4000	6000
Diphasic Recovery Subjects										
G	5	4	6	3	6	3	9		2	0
H	5	2	6	0	8	1	4		0	3
J	0	1	7	1	7	9	9		4	4
K	0	0	9	8	9	6	9		4	5
L	0	2	1	1	0	0	1		1	4
M	0	0	0	2	4	0	1		0	1
Sensitization Subjects										
G	0	3	2	1	0	1	1		0	0
H	0	0	1	0	0	1	2		1	0
J	2	0	3	4	2	6	0		0	0
K	0	1	2	0	6	2	4		2	1
L	4	0	4	11	2	4	5	1	5	0
M	2	9	2	2	4	3	3		3	4
Bounce higher than initial TTS. Subjects										
G	0	0	1	1	6	2	4		2	0
H	0	0	1	0	4	1	4		0	2
J	0	1	0	1	3	4	5		2	1
K	0	0	1	5	0	1	1		2	0
L	0	2	0	1	0	0	0		1	0
M	0	0	0	2	3	0	1		0	1

Part 4.

Experiment. Test tone.

Main Variable. Test tone Frequency (in cps.)

	500	1000	1500	2000	3000	4000	6000	8
Diphasic Recovery Subjects								
N	1	5	3	6	8	2	5	
O	3	7	4	8	11	3	6	
P	3	3	1	4	5	1	3	
Q	7	4	4	3	6	2	1	
R	3	2	3	6	5	0	4	
S	2	3	1	4	2	1	2	
Sensitization Subjects								
N	2	2	5	4	4	6	3	
O	3	2	3	5	3	2	0	
P	5	6	3	0	1	2	6	
Q	5	6	5	8	4	7	3	
R	4	5	6	7	9	0	5	
S	2	9	1	7	8	6	2	
Bounce higher than initial TTS. Subjects								
N	1	3	2	4	5	2	2	
O	1	5	2	4	5	3	0	
P	2	0	1	2	0	1	0	
Q	2	0	1	2	2	1	0	
R	1	0	0	0	1	0	4	
S	1	1	1	4	2	1	2	

Table X11l

Summarizes the result of the analysis of the 1950 individual results for diphasic recovery, sensitization, bounce higher than initial TTS, initial TTS and amount of bounce.

Experiment	Test Frequency in cps.	Stimulus Frequency in cps.	Stimulus Duration in mins.	Stimulus Intensity in db.	Number showing diphasic recovery			Number showing sensitization			Mean initial TTS in db.	Number showing bounce higher than initial TTS.			Mean amount of bounce in db.	Total number of individual results (from 24 subjects).
					Yes	No	Doubtful	Yes	No	Doubtful		Yes	No	Doubtful.		
Part 1.																
Stimulus tone variables (Condition A)	1500	1000	0.5-7.0	70	41	34	9	64	17	3	8.65	5	33	3	3.83	84
"	1500	1000	0.5-7.0	90	53	19	12	63	19	2	14.83	19	23	11	11.51	84
"	1500	1000	0.5-7.0	110	28	53	3	21	62	1	21.25	15	12	1	5.36	84
Part 2.																
Stimulus tone variables (Condition B)	1500	1000	1.0	70-120	47	5	14	46	7	13	10.86	18	24	5	7.68	66
"	1500	1000	2.0	70-120	49	8	9	42	9	15	13.37	26	13	10	12.59	66
"	1500	1000	3.0	70-120	22	43	1	20	27	19	25.18	10	9	3	15.35	66
Part 3.																
Stimulus tone variables (Condition C)	750	500	1.0,2.0 & 3.0	70,90 & 110	10	35	9	8	42	4	1.16	0	7	3	0.86	54
"	1000	750	1.0,2.0 & 3.0	70,90 & 110	9	29	16	13	38	3	4.69	3	5	1	1.28	54
"	1500	1000	1.0,2.0 & 3.0	70,90 & 110	29	14	11	14	43	1	12.38	3	19	7	6.57	54
"	2000	1500	1.0,2.0 & 3.0	70,90 & 110	15	28	11	18	24	12	4.83	10	4	1	2.89	54
"	2500	2000	1.0,2.0 & 3.0	70,90 & 110	34	13	7	14	38	2	9.23	16	16	2	8.17	54
"	3000	2500	1.0,2.0 & 3.0	70,90 & 110	19	25	10	17	33	4	7.96	8	7	4	6.72	54
"	4000	3000	1.0,2.0 & 3.0	70,90 & 110	33	18	3	15	35	4	16.57	15	18	0	12.63	54
"	4250	3500	1.0,2.0 & 3.0	70,90 & 110	33	18	3	29	24	1	15.18	19	11	3	8.33	54
"	6000	4000	1.0,2.0 & 3.0	70,90 & 110	11	38	5	11	39	4	24.26	7	4	0	20.24	54
"	8000	6000	1.0,2.0 & 3.0	70,90 & 110	17	32	5	5	47	2	3.89	7	8	2	2.95	54
Part 4.																
Test tone variables	500	1000 to 6000	1.0 & 3.0	70 & 110	19	98	3	21	95	4	0.86	8	8	3	1.61	120
"	1000	1000 to 6000	1.0 & 3.0	70 & 110	24	81	15	30	84	6	5.58	9	11	4	2.24	120
"	1500	1000 to 6000	1.0 & 3.0	70 & 110	16	94	10	23	88	9	4.18	7	9	0	5.84	120
"	2000	1000 to 6000	1.0 & 3.0	70 & 110	31	89	0	34	81	5	8.39	16	14	1	6.73	120
"	3000	1000 to 6000	1.0 & 3.0	70 & 110	37	75	8	29	89	2	9.65	14	17	6	9.81	120
"	4000	1000 to 6000	1.0 & 3.0	70 & 110	9	104	7	23	87	10	14.13	8	0	1	13.78	120
"	6000	1000 to 6000	1.0 & 3.0	70 & 110	21	93	6	19	95	6	8.17	8	11	2	4.93	120
"	8000	1000 to 6000	1.0 & 3.0	70 & 110	15	101	4	20	98	2	3.62	6	9	0	2.44	120
				Total	589	1180	181	Total 585	1231	134	Total 194.29	Total 246	280	63	Total 170.90	Total 1950
											Mean 8.09				Mean 7.120	

points at the highest threshold value thereafter (see points d, e and f on figure 18a to 18c) were calculated. The difference between these values was recorded as a measure of the amount of bounce. Figures 18a to 18c are examples of records studied in this way and table Xll records the judgements made on these records.

Table Xlll summarizes the results of this analysis. The table is sub-divided into four parts dealing with the experiments on the stimulus tone variables, Conditions 'A', 'B' and 'C' and the experiments on the test tone variables respectively. Inspection of parts 1 and 2 of the table reveal that the proportion of results showing diphasic recovery is maximal at a stimulus intensity of 90 db. and at a stimulus duration of 2 minutes. Parts 1 and 2 also reveal that the proportion of results showing sensitization and the proportion of results showing bounce higher than initial TTS decrease and increase respectively with increased severity of the stimulus conditions. Parts 3 and 4 of the table reveal that the presence of diphasic recovery is maximal at 1000, 2000 and 3000 cps and is minimal at 4000 cps. Sensitization, in these sections, is minimal at 2000, 3000, 4000 and possibly 1000 cps, and bounce higher than initial TTS is maximal at 4000 cps and minimal at 1000, 2000 and 3000 cps.

In order to test the validity of the judgements made, the <u>total</u> results for all conditions were analysed using a chi-squared test (see Garrett, 1958, pages 253 to 266). It would be expected that if no trend were apparent, a third of the total results would be assigned to the yes, no and doubtful categories in the sections on diphasic recovery, sensitization and bounce higher than initial TTS. For example a total of 702 results showed diphasic recovery, 1067 did not show diphasic recovery and 181 were doubtful. These are the obtained frequencies and the expected frequencies are 650 in each case (one third of 1950). The results of the chi-square analysis are summarized in table XlV. It can be seen from the table that in all cases the assignment of the results is significantly different from chance.

To treat the data statistically it was necessary to use the results obtained with individual subjects. These are presented in table XV (parts 1 to 4). Only the "yes" classifications are shown in the table

Table XVI

Summarizes the results of the Friedman two-way analysis of variance applied to the data of table XlV.

Experiment	Factor	Number of Columns (Experimental Conditions)	Number of Rows (Subjects)	χ_r^2	Probability.
Stimulus tone (Condition 'A')	Diphasic Recovery	3	6	8.333	0.012
"	Sensitization	3	6	10.333	0.0017
"	Bounce higher than initial TTS	3	6	6.333	0.052
Stimulus tone (Condition 'B')	Diphasic Recovery	3	6	7.000	0.029
"	Sensitization	3	6	8.333	0.012
"	Bounce higher than initial TTS	3	6	2.333	0.430
Stimulus tone (Condition 'C')	Diphasic Recovery	10	6	17.381	Less than 0.05
"	Sensitization	10	6	17.863	Less than 0.05
"	Bounce higher than initial TTS	10	6	45.072	Less than 0.001

Table XVl continued

Experiment	Factor	Number of Columns (Experimental Conditions)	Number of Rows (Subjects)	χ_r^2	Probability.
Test Tone	Diphasic Recovery	8	6	20.305	Less than 0.01
"	Sensitization	8	6	6.319	Less than 0.50
"	Bounce higher than initial TTS	8	6	4.083	Less than 0.80

since the total number of "no" and "doubtful" cases is determined by the number of "yes" classifications. The data on diphasic recovery, sensitization and bounce higher than initial TTS and the data in each part of the table were analysed separately. If we are to test the differences within the different experimental conditions, the samples in table XV cannot be treated as being independent. The same subject was used to collect the data within any particular series of experimental conditions. Hence, it was necessary to use a Friedman two-way analysis of variance (see Siegel, 1956, pages 166 to172) to test the significance of the data. This is a non-parametric test used when "k matched samples are in at least an ordinal scale." (Siegel, page 166). To place the data in an ordinal scale it was necessary to divide the number of cases in any cell by the possible total number of cases. However, for the data on diphasic recovery and sensitization in any given part of the table, the divisor was always the same. For example, in part 1 there are 14 possible cases in any cell in the diphasic recovery and sensitization sections. Consequently, the ordinal ranking utilized in the analysis of this data was based on the number of cases of diphasic recovery or sensitization. However, for the data on bounce higher than initial TTS the divisor varied, since the total number of possible cases was equal to the number of cases showing diphasic recovery. Hence, for this data the ordinal ranking was based on the number of cases divided by the possible total number of cases.

Table XVl summarizes the results of the Friedman two-way analysis of variance used to test the significance differences within different experimental conditions. It can be seen from this table that the following differences are not significant at either the 0.05 or the 0.01 level of confidence :

(i) The differences in the degree of bounce with different stimulus intensities (stimulus tone experiments, Condition 'A').

(ii) The differences in the degree of bounce with different stimulus durations (stimulus tone experiments, Condition 'B').

(iii) The differences in sensitization with different test tone frequencies (Test tone experiments).

(iv) The differences in the degree of bounce with different test tone frequencies (Test tone experiments).

Table XV11

Summarizes the results for individual subjects of the presence of diphasic recovery, sensitization and bounce higher than initial TTS.

Part 1. Stimulus Tone: Condition 'A'.	Subject.					
	A	B	C	D	E	F
No. Diphasic	28	16	35	20	5	18
No. Monophasic	8	26	6	15	32	24
No. Doubtful	6	5	1	7	5	0
No. Sensitization	31	38	21	29	9	20
No. Non-Sensitization	9	4	18	13	32	22
No. Doubtful	2	0	3	0	1	0
No. Bounce Higher	15	10	4	4	4	2
No. Bounce Lower	12	6	29	14	1	6
No. Doubtful	1	0	2	2	0	10

Part 2. Stimulus Tone: Condition 'B'.	Subject.					
	A	B	C	D	E	F
No. Diphasic	18	20	23	23	24	10
No. Monophasic	10	9	5	7	7	18
No. Doubtful	5	4	5	3	2	5
No. Sensitization	22	16	15	24	9	22
No. Non-Sensitization	9	11	5	4	8	6
No. Doubtful	2	6	13	5	16	5
No. Bounce Higher	11	10	14	6	7	6
No. Bounce Lower	2	8	5	14	14	3
No. Doubtful	5	2	4	3	3	1

..........cont.

Table XV11 (continued).

Part 3. Stimulus Tone: Condition 'C'.	Subject					
	G	H	J	K	L	M
No. Diphasic	47	33	51	59	12	8
No. Monophasic	30	48	33	14	67	58
No. Doubtful	13	9	16	7	11	24
No. Sensitization	10	7	21	24	45	37
No. Non-Sensitization	75	79	61	57	38	49
No. Doubtful	5	4	8	9	7	4
No. Bounce Higher	21	14	26	11	6	4
No. Bounce Lower	21	13	22	39	4	4
No. Doubtful	5	6	3	9	0	0

Part 4. Test Tone.	Subject					
	N	O	P	Q	R	S
No. Diphasic	32	42	21	33	27	17
No. Monophasic	120	112	131	120	122	130
No. Doubtful	8	6	8	7	11	13
No. Sensitization	27	19	23	43	40	44
No. Non-Sensitization	130	127	133	110	109	112
No. Doubtful	3	14	4	7	11	5
No. Bounce Higher	21	20	7	9	5	14
No. Bounce Lower	6	19	10	22	17	3
No. Doubtful	5	3	4	2	5	0

Table XVlll

Summarizes the results of the chi-square analysis of table XVll to test the significance of the subject differences. If necessary the monophasic and doubtful, non-sensitization and doubtful and bounce lower and doubtful rows have been combined to fulfill the requirements of chi-square.

Experiment	Factor	Chi-square	d.f.	Significance.
Stimulus Tone (Condition 'A')	Diphasic Recovery	85.12	5	Less than 0.01
"	Sensitization	48.78	5	Less than 0.01
"	Bounce	19.65	5	Less than 0.01
Stimulus Tone (Condition 'B')	Diphasic Recovery	22.11	5	Less than 0.01
"	Sensitization	35.83	5	Less than 0.01
"	Bounce	21.75	5	Less than 0.01
Stimulus Tone (Condition 'C')	Diphasic Recovery	100.87	10	Less than 0.01
"	Sensitization	69.8	5	Less than 0.01
"	Bounce	15.758	5	Less than 0.01
Test Tone	Diphasic Recovery	36.62	10	Less than 0.01
"	Sensitization	39.32	5	Less than 0.01
"	Bounce	15.758	5	Less than 0.01

Apart from these all the other conclusions reached after inspection of table X111 (see page 102) are statistically significant at the 0.01 or 0.05 level of confidence.

To analyse the data even further a second table was drawn up showing the results for individual subjects. This is table XV11, (parts 1 to 4). It can be seen from this table that the individual subjects vary considerably in the degree to which they show diphasic recovery, sensitization and a bounce higher than the initial TTS. To test the significance of these differences 12 contingency tables were constructed and the data analysed using chi-squared. (See siegel, 1956, pages 175 to 179). The 12 contingency tables consisted of the results for diphasic recovery, sensitization and a bounce higher than the initial TTS, separately analysed for the three stimulus tone experiments and for the test tone experiments. The justification for using chi-square is that the results for each individual subject can be considered to be independent. Hence, the samples (i.e. the results for each individual subject) are independent. In table XV11 it can be seen that there are several sections in which more than 20 per cent of the expected cell values are less than 5 and/or any expected cell values are less than 1. Siegel (op.cit., page 178) points out that under these conditions "the results of the test are meaningless." However, Siegel also points out that this difficulty can be obviated by combining adjacent categories, provided that the adjacent categories have some common property. In table XV11, both the categories not showing a given phenomenon can be combined meaningfully, i.e. they become single category recording the number of cases not showing the given phenomenon. Hence, wherever necessary the "doubtful" cases were combined with the number of cases showing monophasic recovery, non-sensitization or a bounce lower than the initial TTS. When this was done, it was found that the requirements for chi-square were not violated. The results of this analysis are summarized in table XV111. It can be seen from the table that under all experimental conditions the differences in diphasic recovery, sensitization and a bounce higher than the initial TTS are significant at the 0.01 level of confidence. Hence, we can conclude that there are significant individual differences in susceptibility to diphasic recovery, sensitization and bounce higher than the initial TTS.

Table XlX

Summarizes the results of the chi-square analysis of table XVll to test the interelationships between diphasic recovery, sensitization and bounce.

Experiment	Chi-square	Degrees of freedom	Significance
Stimulus Tone (Condition A)	36.579	5	At 0.01 level
Stimulus Tone (Condition B)	7.758	5	Not significant
Stimulus Tone (Condition C)	46.598	5	At 0.01 level
Test Tone	20.437	5	At 0.01 level

Further inspection of table XV11 reveals that those subjects with the highest proportion of results showing diphasic recovery tend to be those subjects with the lowest proportion of results showing sensitization. Similarly, those subjects with the highest proportion of results showing diphasic recovery tend to be those subjects with the highest proportion of results showing a bounce higher than the initial TTS. To test this hypothesis a second contengency table was drawn up for each part of table XV11. In this the number of results showing diphasic recovery, the number of results showing sensitization and the number of results showing bounce higher than initial TTS were plotted as rows. The following exemplifies the procedure with part 1 of table XV11 :

	Subject					
	A	B	C	D	E	F
No. Diphasic	28	16	35	20	5	18
No. Sensitization	31	38	21	29	9	20
No. Bounce higher than initial TTS	15	10	4	4	4	2
TOTAL	74	64	60	53	18	40

These tables were subject to a chi-squared analysis. It was again necessary to combine rows to avoid violation of the assumptions made in chi-square (see page 108). In this case the results for sensitization and bounce were combined. The results of the analysis are summarized in table XlX. It can be seen from this table that in three out of four of the experimental conditions the results are significantly different at the 0.01 level of confidence. Consequently, the two observations are justified.

CHAPTER X

Control Experiments.

Five control experiments were carried out (see pages 59 to 63). They were :

(i) Experiments in which the stimulus tone was replaced by a period of silence.

(ii) Experiments in which the Békésy method of threshold tracing was compared with threshold measurements obtained using a modified method of limits.

(iii) Experiments comparing the tracing of thresholds, using the Békésy method, for short periods and for long periods.

(iv) Experiments on long term TTS effects.

(v) Experiments studying the ambient noise levels in the sound-proof room.

The results obtained in these experiments are described in the subsequent sections.

(a) Stimulus tone replaced by silence :

Figures 19a to 19c illustrate the tracings obtained when the stimulus tone was replaced by a period of silence. It can be seen from the tracings that there is very little observable shift in threshold under these conditions. To check this the mean pre-exposure and post-exposure thresholds were calculated by taking the mean of the transition points in these periods. The mean shift in the 54 control trials (6 subjects with 9 experimental conditions) was found to be -1.39 db. The standard deviation of these results was 1.47 db.

(b) The Békésy Method :

Initially in these experiments the six subjects traced their threshold using the Békésy method, for one fifteen minute period at frequencies of 1000, 1500, 2000, 3000, 4000 and 6000 cps. In this way 36 tracings were obtained. Figures 20a to 20c are representative examples of the tracings obtained in this manner. Inspection of these and the other 33 tracings obtained revealed that slow aperiodic changes occured in the threshold during the 15 minute tracing period. In order to

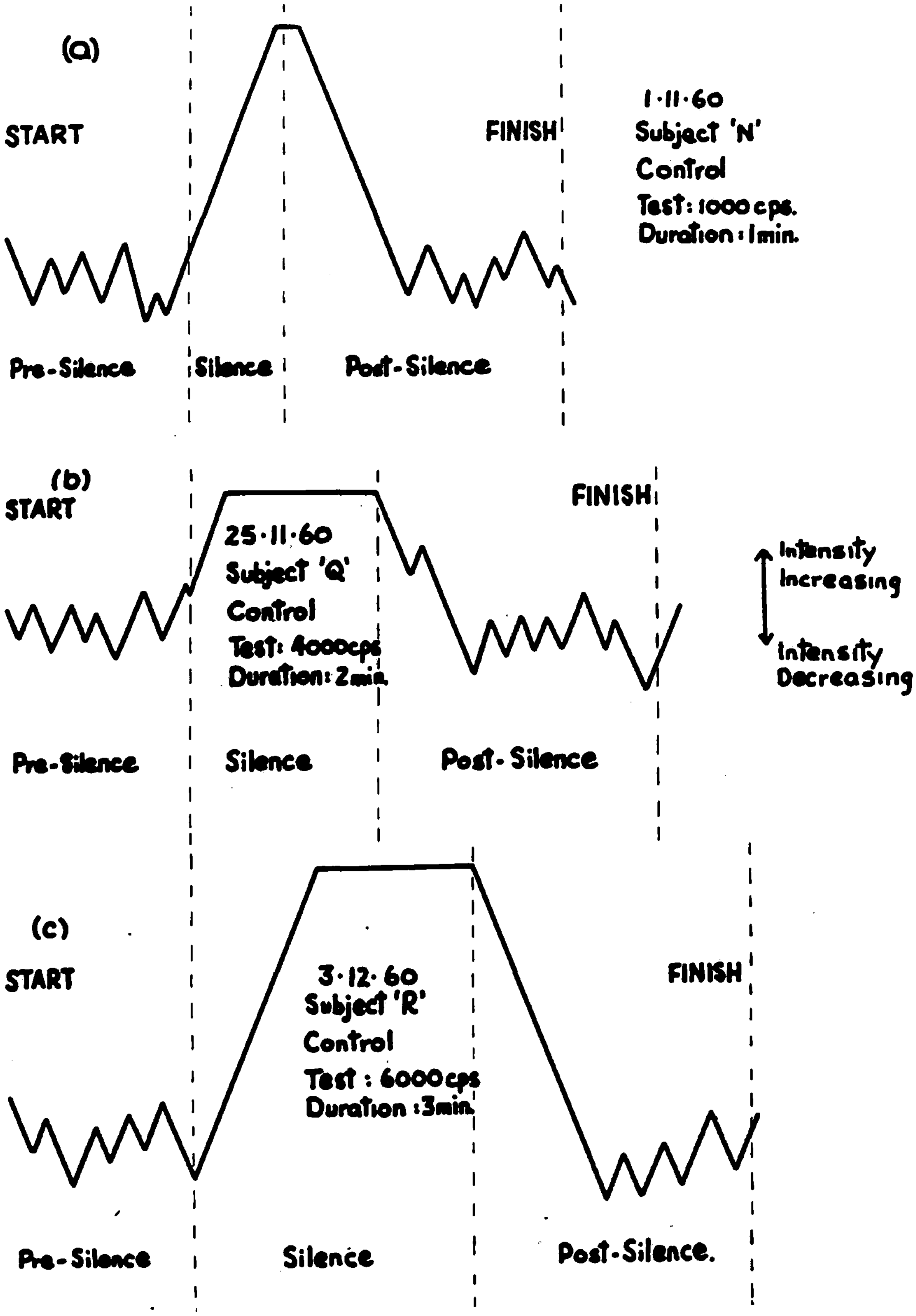


Figure 19: Typical tracings obtained when a period of silence replaced the stimulus tone. Time left to right (1" to 1.5 min.). Intensity top to bottom (1" to 8.08 db.).

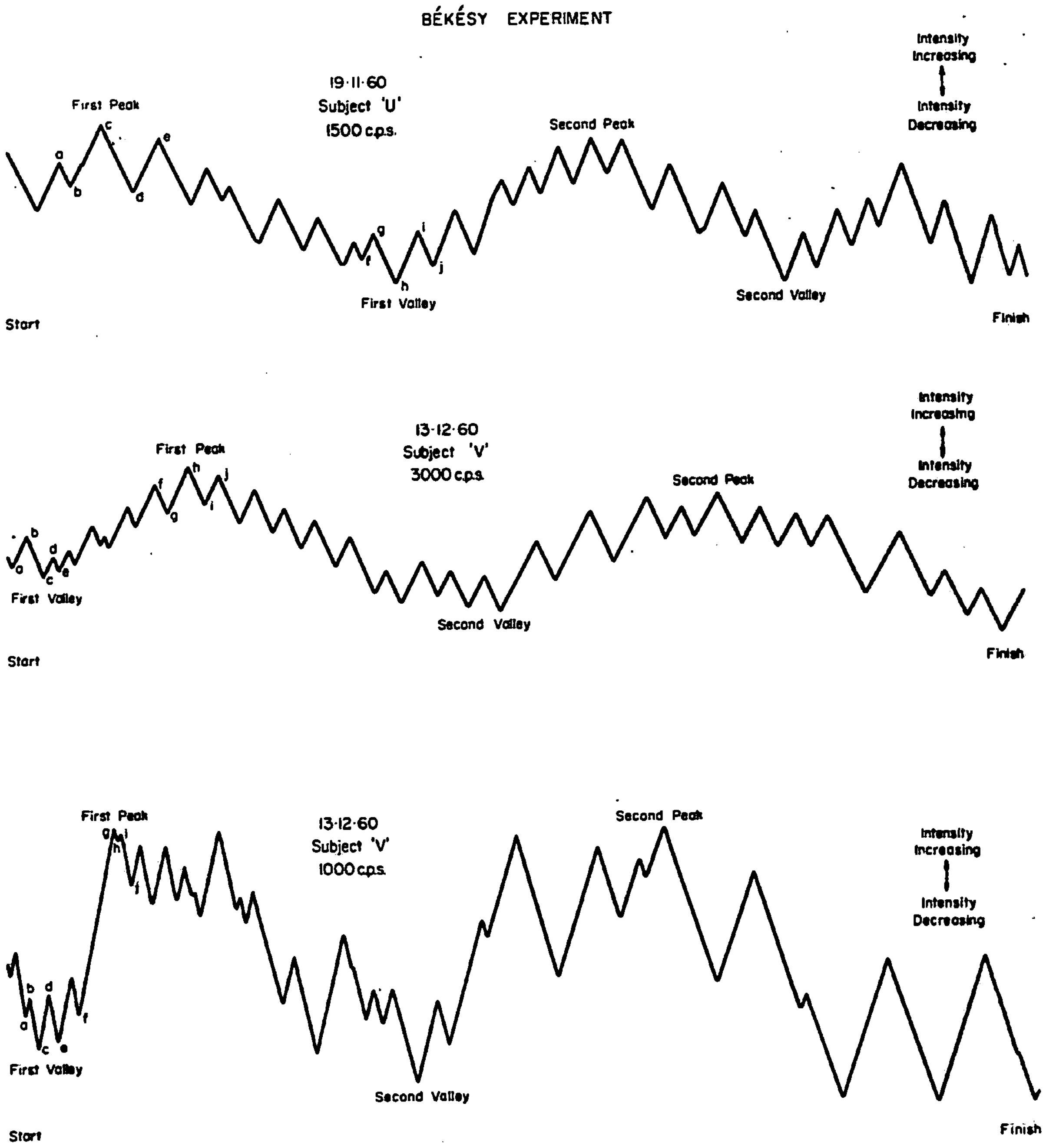


Figure 20 : Shows typical tracings obtained when the threshold is traced for a fifteen minute period using the Bekesy technique. Test frequency is as shown and was constant throughout the tracing period. Scale : Intensity, I inch to 15.6 db; Time 1 inch to 2.3 minutes.

Table XX

Shows the amount of threshold oscillation for each subject at each frequency, for each subject with all frequencies and for each frequency with all subjects (measured by the number of peaks and valleys on a fifteen minute test record).

	Frequency in cps.							
	1000	1500	2000	3000	4000	6000	Total	Mean
Subject T	5	8	3	5	4	1	26	4.50
" U	6	8	6	3	2	0	25	4.16
" V	7	11	6	4	3	1	32	5.33
" W	4	5	4	3	2	0	18	3.00
" X	2	4	4	2	2	1	15	2.50
" Y	5	7	7	3	2	1	25	4.16
Total	29	44	30	20	15	4	141 = Grand Total	
Mean	4.83	7.33	5.00	3.33	2.5	0.66		3.94 = Grand Mean

facilitate the investigation, each record was quantified in the following manner :

(i) The number of peaks and valleys, i.e. the extremes of threshold values and not the transition points, were counted. This is termed the amount of oscillation.

(ii) The threshold value at each peak and valley were computed by averaging the five transition points surrounding it (see a, b, c, d and e; and f, g, h, i and j etc. on figures 20a to 20c).

(iii) The differences between the threshold at successive peaks and valleys was calculated. This was averaged to provide a mean value of the amplitude of the threshold oscillation.

(iv) The subjects were ranked by reference to the mean amount of oscillation that they showed on the six tracings which were available for each subject.

(v) The subjects were ranked by reference to the mean amplitude of oscillation that they showed on the six tracings which were available for each subject.

Table XX shows the amount of oscillation produced by each subject at each of the frequencies tested. Inspection of the table reveals that the amount of oscillation is maximal at 1500 cps and decreases as the frequencies deviate from this value. The table also indicates that there are significant differences between subjects in the amount of oscillation that they show. These differences were not tested using analysis of variance, since it was suspected that the distribution of the amount of oscillation might be badly skewed. Oldfield (1955) states of similar fluctuations in the differential threshold for sound intensity that, "the population of values is highly skewed, and neither logarithmic nor square root transformation

Table XXI

Summarizes the analysis of the data presented in table XX, to test whether the frequency and subject differences in amount of oscillation are significant.

(a) Frequency differences: Friedman's two-way analysis of variance.

Sum of column ranks squared = 3163.50
Number of rows = 6
Number of columns = 6
Degrees of freedom = 5

$\chi_r^2 = 14.642$ (P less than 0.02)

(b) Subject differences: Kruskal-Wallis one-way analysis of variance (incorporating the correction for tied ranks).

Number of samples = 6
Number of cases in each sample = 6
Total number of cases = 36
Sum of sample ranks squared = 75730.00
Degrees of freedom = 5
Correction for tied ranks = 0.995

H = 2.721 (P between 0.80 and 0.70)

Table XXII

Shows the mean amplitude of oscillation (in db.) for each subject at each frequency, for each subject with frequencies of 1000, 1500, 2000 and 3000 and 4000 cps and the means for all subjects (a dash indicates insufficient peaks and valleys were available to determine the amplitude of the oscillation).

Frequency in cps.

		1000	1500	2000	3000	4000	6000	Total	Mean
Subject	T	14.84	6.59	14.36	7.43	5.50	-	43.25	10.81
"	U	4.51	4.00	4.75	8.81	5.08	-	22.07	5.52
"	V	3.99	2.55	3.92	6.72	2.32	-	17.18	4.30
"	W	6 .62	7.18	7.12	13.12	8.50	-	34.06	8.51
"	X	7.87	5.58	8.58	5.62	4.75	-	27.66	6.92
"	Y	3.76	1.21	5.01	4.76	14.00	-	14.74	3.69
Total		41.6	27.11	43.74	46.0	30.15	-	Grand Total = 158.96	
Mean		6.93	4.51	7.29	7.66	5.03	-		Grand Mean = 6.623

Table XX111

Summarizes the analysis of the data presented in table XX11, to test whether the frequency and subject differences in amplitude of oscillation are significant.

(a) Frequency differences: Friedman's two-way analysis of variance.

Sum of column ranks squared	=	974
Number of rows	=	6
Number of columns	=	4
Degrees of freedom	=	3

$\chi_r^2 = 7.4$ (P between 0.20 and 0.10)

(b) Subject differences: Kruskal-Wallis one-way analysis of variance.

Number of samples	=	6
Number of cases in each sample	=	4
Total number of cases	=	24
Sum of sample ranks squared	=	17,510
Degrees of freedom	=	5

$H = 12.50$ (P less than 0.05)

goes far to normalize it." Similarly in discussing fluctuations of the absolute threshold for sound intensity, Wertheimer (1953) states that "non-parametric techniques were employed in preference to standard ones." The significance of the frequency differences were tested using Friedman's two-way analysis of variance (see Siegel, 1956, pages 166 to 172). The justification for using this technique has been outlined on page 105. To test the subject differences the data was tested using the Kruskal-Wallis one-way analysis of variance (see Siegel, op.cit. pages 184 to 193). The justification for using this technique is that if we treat the subjects as conditions, the samples are independent. The Kruskal-Wallis test was used in preference to chi-square because the data is in an ordinal scale.

The results of the two analysis are summarized in table XXl. It can be seen from the table that the frequency differences in the amount of oscillation are significant at the 0.02 level of significance, but that the subject differences are not significant. The latter finding is probably an artifact of the shortness of the test period. For most subjects only one or two peaks and valleys occurred at 4000 and 6000 cps. A longer period would have allowed a more accurate assessment of the number of peaks and valleys. Hence, subject differences would have been increased.

The data obtained regarding the amplitude of oscillation was treated in a similar manner. Table XXll shows the mean amplitude of oscillation at each frequency for each subject and the mean at each frequency for all subjects. In the analysis the results at 4000 cps were discarded, since these were obtained from only two or three peaks and valleys and hence were thought, as a group, to be unreliable. The results of the analysis are summarized in table XXlll. It can be seen from the table that the frequency differences are not significant, but that the subject differences are significant at the 0.05 level of confidence.

Inspection of the mean values in the body of table XX and in the body of table XXll indicates that there appears to be some negative relationship between the amount and the amplitude of the oscillations.

Table XXIV

Calculation of Spearman's rank differences correlation coefficient for the rankings of the mean amount and mean amplitude of oscillation for the different subjects.

Subject	X Mean amount of oscillation. (See table XIX).	Y Mean amplitude of oscillation. (See table XXI).	x Rank for amount.	y Rank for amplitude.	d	d^2
V	5.33	4.33	1	5	4	16.00
T	4.50	10.8	2	1	1	1.00
U	4.17	5.5	3.5	6	2.5	6.25
Y	4.17	3.69	3.5	4	0.5	0.25
W	3.00	8.51	5	3	2	4.00
X	2.50	6.92	6	2	4	16.00

Rank differences correlation coefficient = 0.23

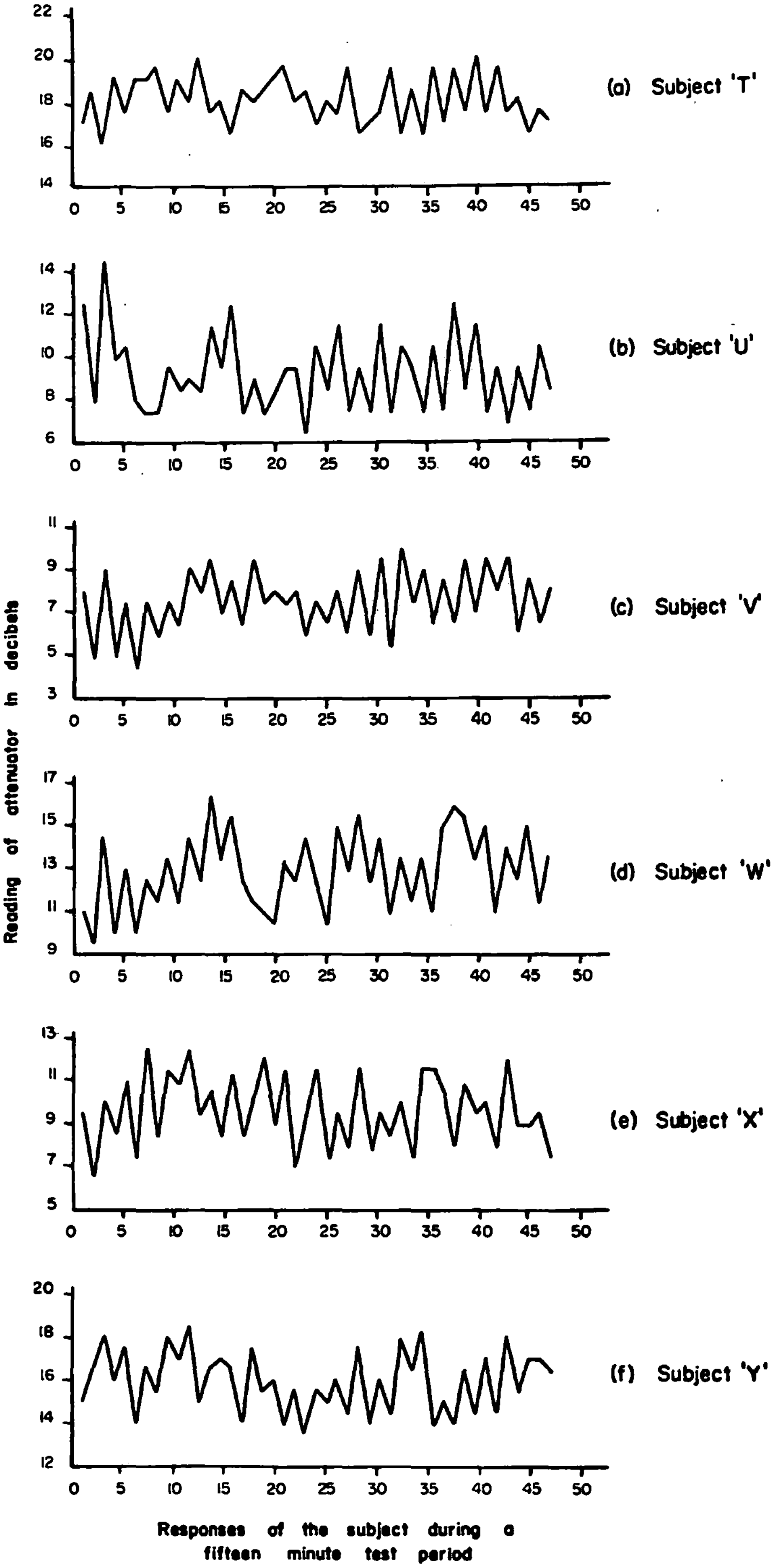


Figure 21 : Shows the threshold responses made by the subjects when the threshold was traced for a fifteen minute period using the modified method of limits. Test frequency was 1500 cps throughout.

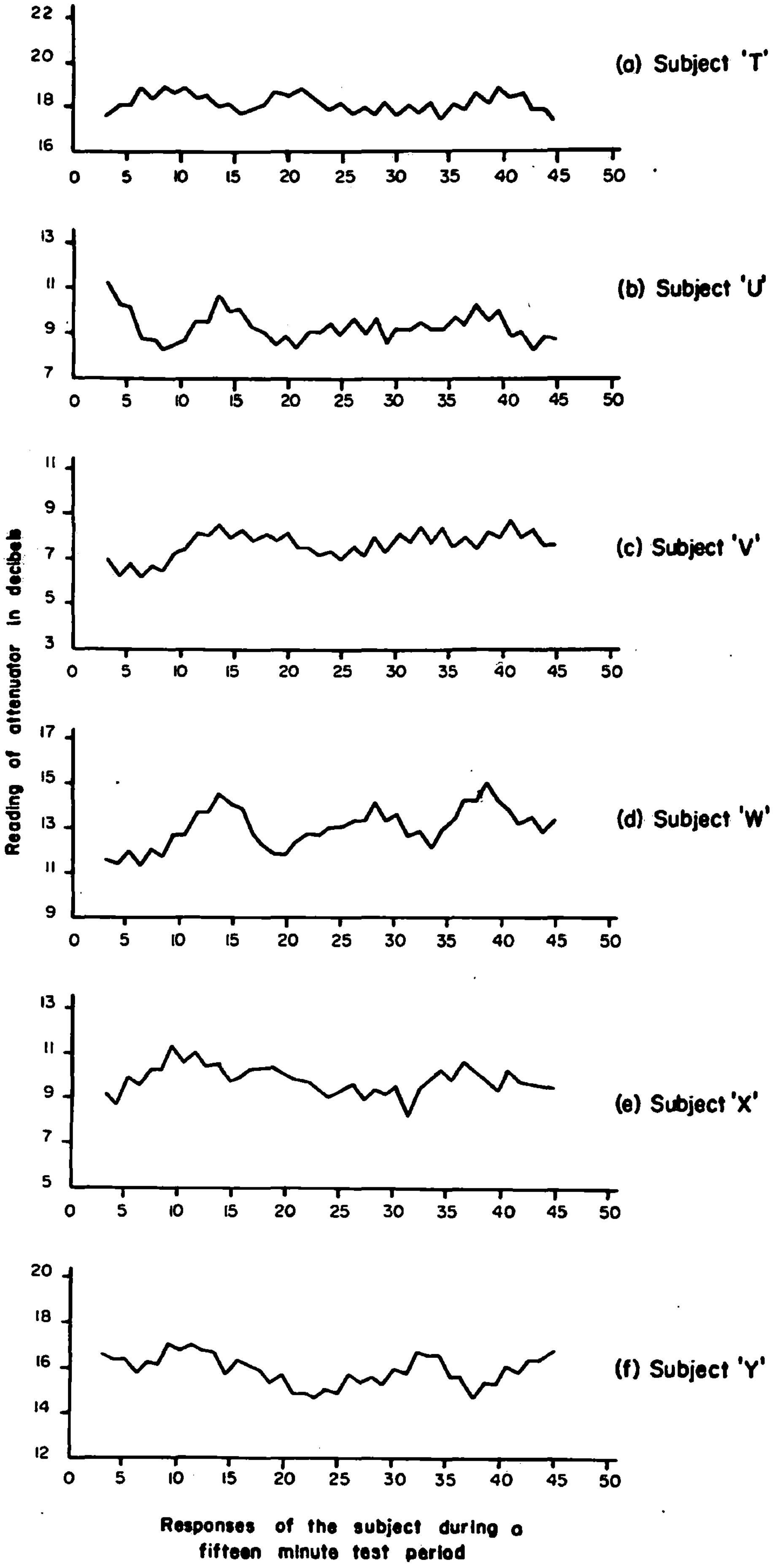


Figure 22 : Shows the effect of smoothing on the threshold responses shown in figure 21. Data was obtained using the modified method of limits with a 1500 cps test frequency. Smoothing was obtained by taking a five-point moving average.

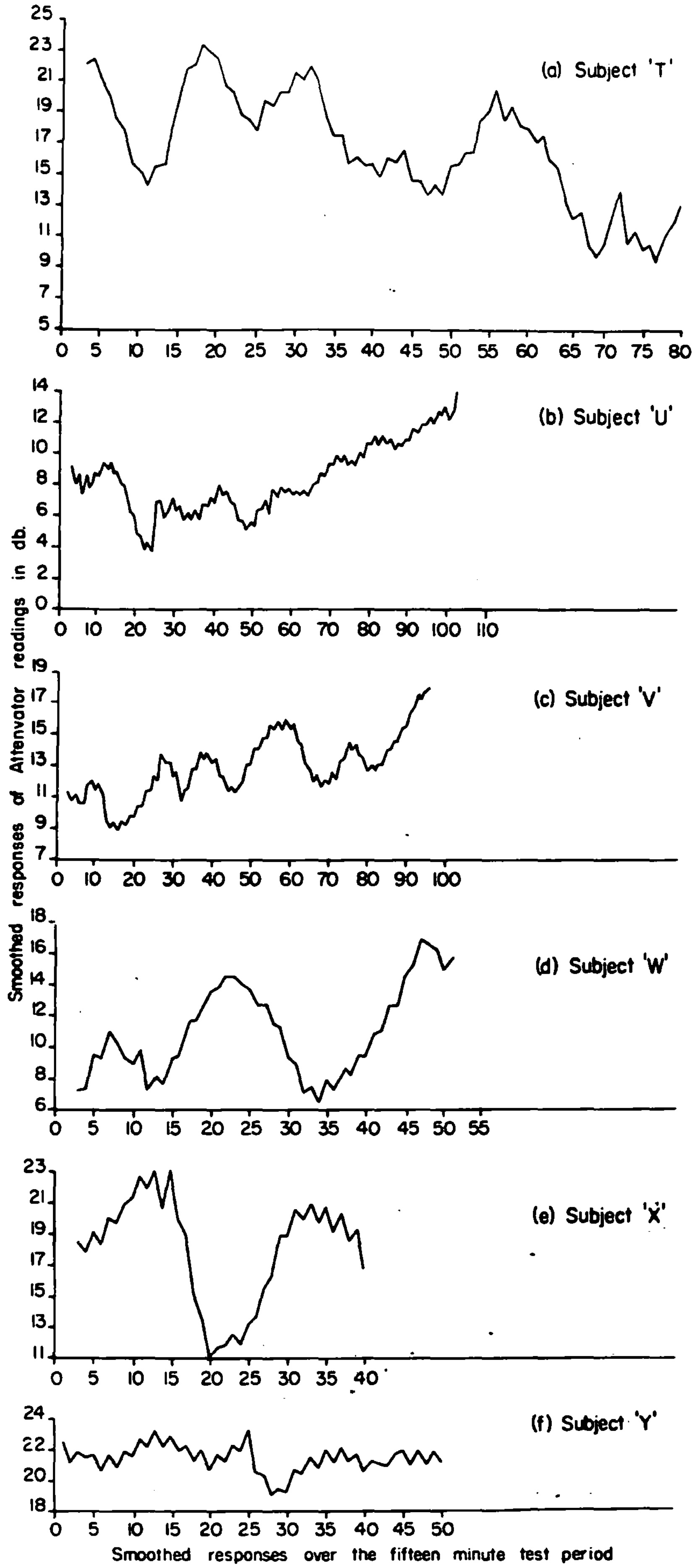


Figure 23: The smoothed threshold responses obtained during a fifteen minute Békésy tracing period at 1500 cps. Smoothing was obtained by taking a five-point moving average.

To test this observation the subjects were ranked by reference to their mean amount of oscillation and by reference to their mean amplitude of oscillation. Spearman's rank-differences correlation coefficient was calculated, after applying a correction for tied ranks (see Yule and Kendall, 1950, page 265). The results of this analysis are summarized in table XXIV. The rank-differences coefficient was found to be -0.23 and this confirms that there is a slight negative relationship between the amount and the amplitude of the oscillatory changes. However, the relationship is not significant since with 6 cases, a coefficient of 0.829 is required for significance at the 0.05 level of confidence (see Siegel, op. cit., pages 210 to 212).

To ascertain whether the changes shown in the Békésy recordings were an artifact of the method used, data was collected for the same subjects using a modified method of limits (see pages 60 to 61). Each subject's threshold was recorded for a fifteen minute period at 1500 cps using this method. The responses made by the subject in this period are shown in figures 21a to 21f. Inspection of these figures reveals that again there are aperiodic oscillatory changes in the threshold. However, intra-subject comparison with the results obtained at 1500 cps using the Békésy technique indicated that the changes produced by the latter method were much greater.

To facilitate the comparison the two sets of curves were smoothed by taking a simple five-point moving average (see Yule and Kendall, 1950, pages 617 to 633). This technique smooths out any chance irregularities in the curves without destroying the general trands. The smoothed curves for the two techniques are shown in figures 22a to 22f and figures 23a to 23f. Visual comparison of the two curves indicates that there is a much greater variation in both the amount and the amplitude of variations using the Békésy technique. The difference in threshold oscillation between the two techniques was statistically tested by calculating for each subject, the mean amplitude of oscillation. Since the same subjects were used in each sample it was necessary to utilize a test for related samples, to test the significance of the differences between the two methods. The non-parametric Wilcoxon matched-pairs

Table XXV

Summarizes the calculation of the Wilcoxon matched-pairs signed-ranks test. This was used to test the significance of the difference between the amplitude of threshold oscillation produced by the Bekesy method and the modified method of limits. Data is presented in figures 22 and 23.

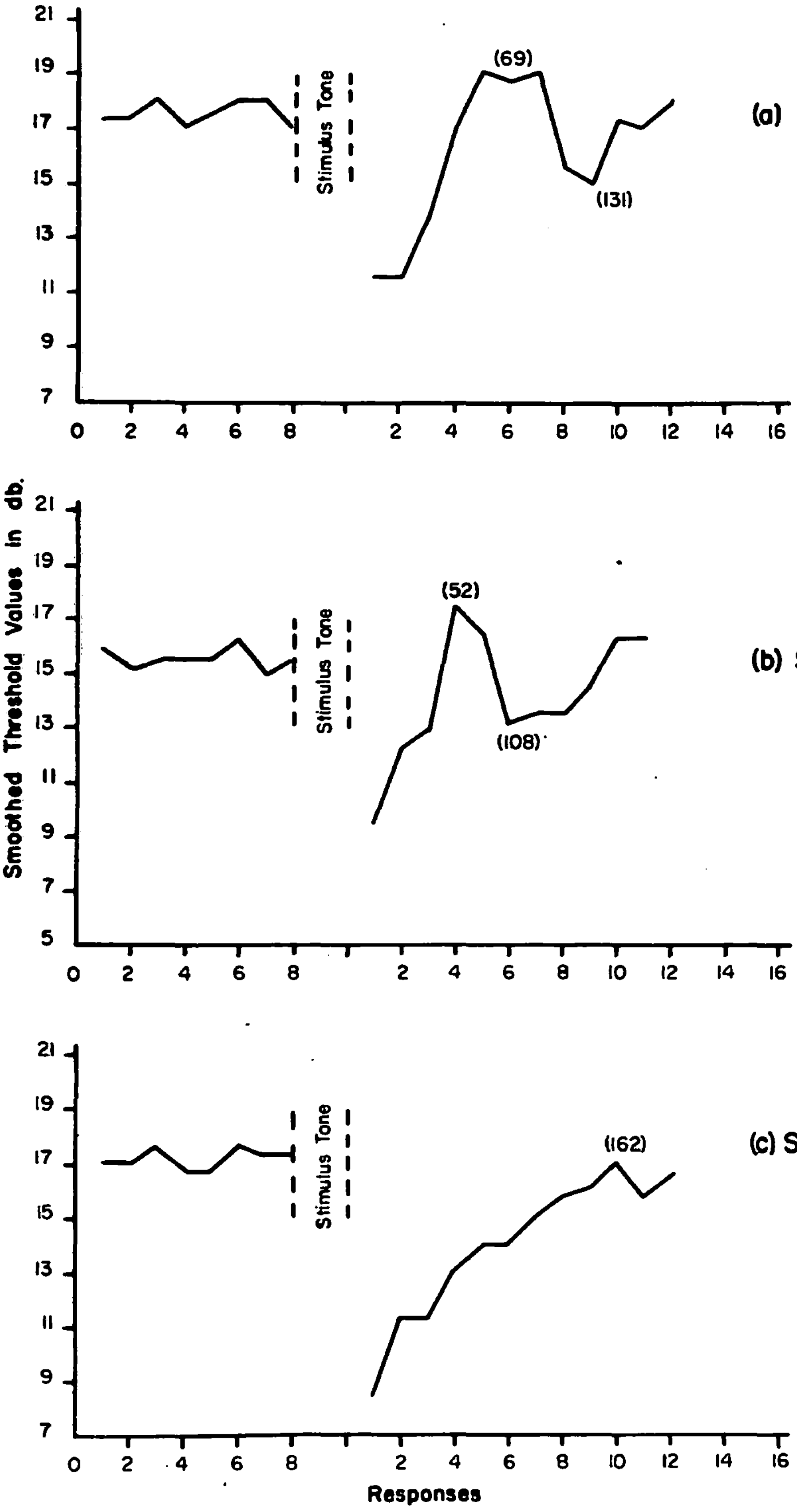
Subject	Mean amplitude-Bekesy method.	Mean amplitude-Method of limits.	d	Rank of 'd'
T	7.30	1.23	6.07	+5
U	3.46	1.86	1.60	+1
V	3.93	1.35	2.58	+3
W	5.80	2.57	3.23	+4
X	10.90	1.48	9.42	+6
Y	3.71	1.80	1.91	+2

There are no negative ranks

Therefore T = 0

With N = 6 and T of 0, the
differences are significant
at the 0.05 level of confidence.

Subject 'G'



(a) Stimulus Intensity 70db.

(b) Stimulus Intensity 90db.

(c) Stimulus Intensity 110db.

Figure 24a: Shows typical recovery curves from TTS. Obtained using modified method of limits, with a 1000 cps stimulus tone and a stimulus duration of 1 minute. Responses have been smoothed using a five-point moving average. Figures in parenthesis are time in seconds.

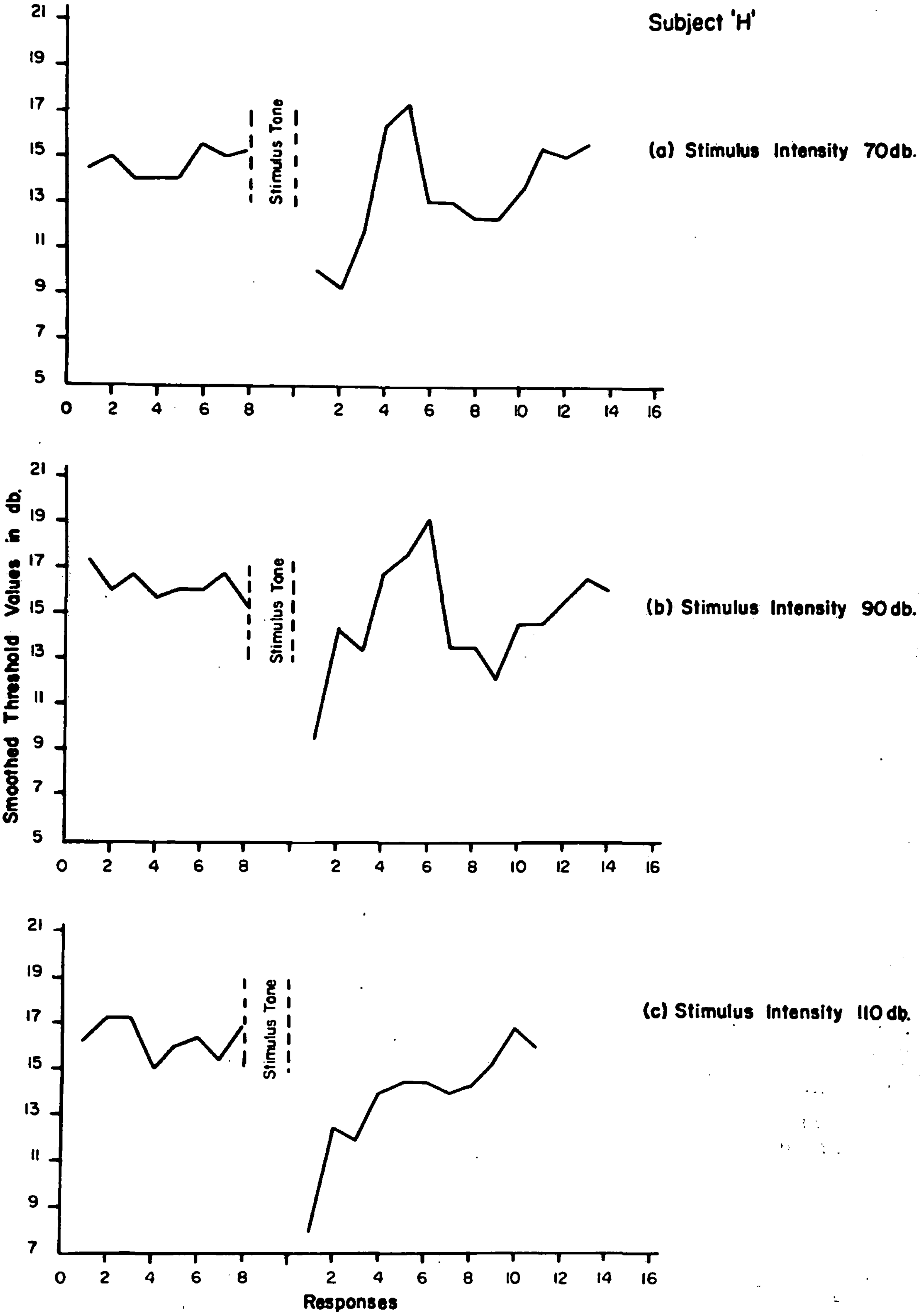


Figure 24b : More typical recovery cures from TTS. Obtained using the modified method of limits with a 1000 cps stimulus tone and a stimulus duration of 2 minutes.

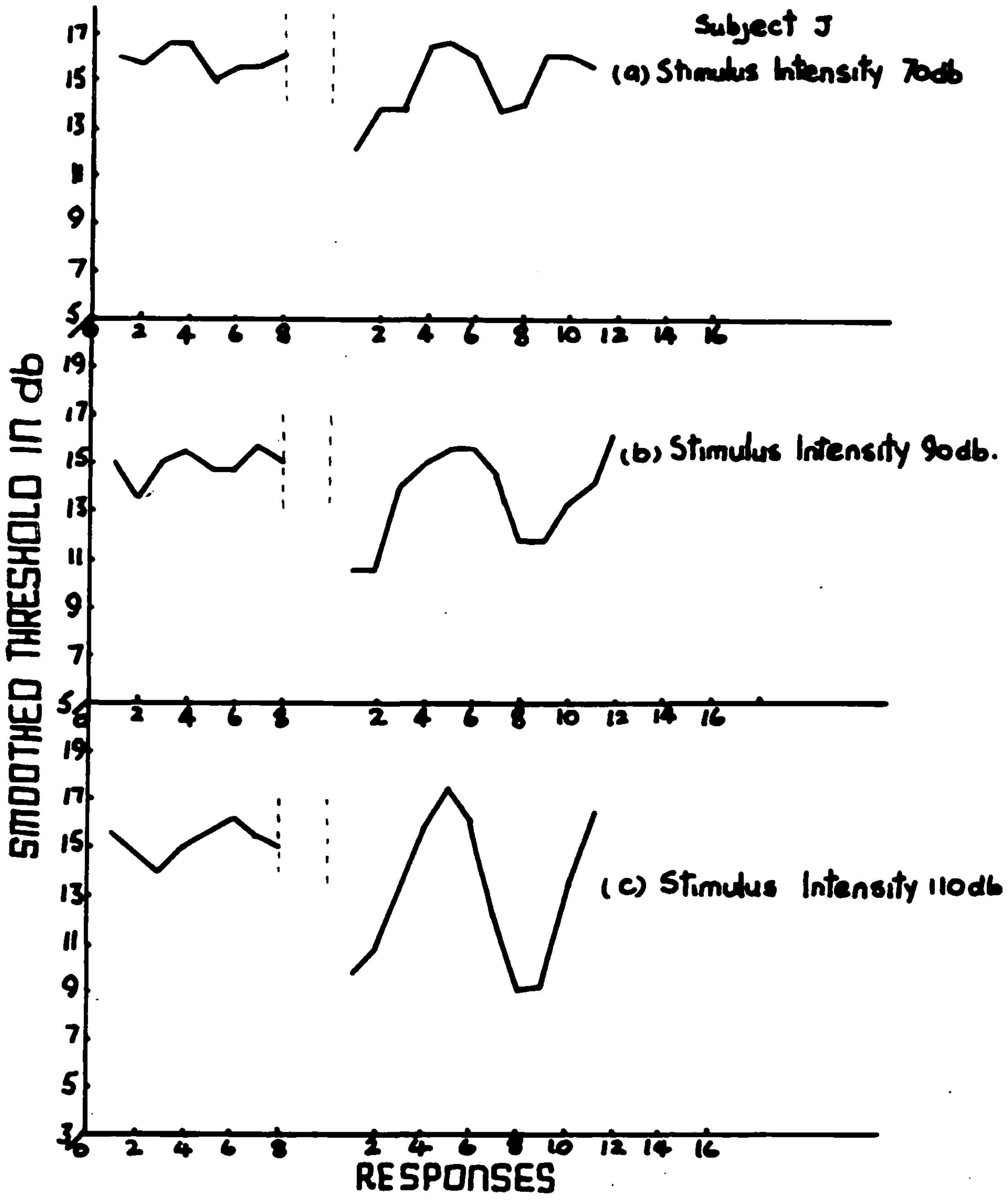


Figure 24c: More graphs of recovery from TTS obtained using the modified method of limits.

Table XXVI

Summary of the analysis of the recovery from TTS using the modified method of limits technique to measure the thresholds.

	Yes	No	Doubtful	Total
Diphasic Recovery	36	9	9	54
Sensitization	16	37	1	54
Bounce higher than initial TTS.	12	16	8	54

signed-ranks test (see Siegel, op, cit., pages 75 to 83) was used. The choice of a non-parametric test was determined by the non-normality of the distribution (see page 115). The Wilcoxon test was used in preference to others such as the Sign Test (see Siegel, op. cit., pages 68 to 75) because it takes account of the magnitude of the differences between the means. The calculations are summarized in table XXV. It can be seen from this table that the differences are significant at the 0.05 level of confidence, or if we assume a one-tailed test, at the 0.025 level of confidence.

(c) Control experiments on recovery from TTS.

Figures 24a to 24c are graphical representations of the results obtained when TTS was studied using the modified method of limits technique to measure the pre-exposure and the post-exposure thresholds. The curves have been smoothed by taking a five-point moving average. The fifty four curves obtained were analysed in the same manner as the recovery curves obtained using the Bekesy method (see page 94). The results of this analysis are summarized in table XXVl.

To compare the recovery phenomena associated with the two techniques, a chi-squared analysis was applied to the data obtained in these experiments and the data collected under similar conditions but using the Bekesy method. (See table Xlll, part 1). The justification for using chi-squared is that the data was collected with two different groups of subjects, i.e. the samples are independent. Three contingency tables were drawn up for the three phenomena as exemplified, for diphasic recovery, in the following table :

Table : Number showing diphasic recovery

All stimulus intensities.

	Bekesy Method	Method of Limits	Total
Yes	122	36	158
No	106	9	115
Doubtful	24	9	33
Total	252	54	306

The table was then analysed using chi-squared (see Siegel, op.cit., pages

Table XXVll

Summarizes the results of the chi-square analysis of the distribution of results showing diphasic recovery, sensitization and bounce higher than initial TTS using the Békésy and modified method of limits technique of threshold measurement. Data used is presented in table Xlll, part 1 and in table XXVl.

Variable	Chi-Square	d.f.	Significance
Diphasic Recovery	12.624	2	At 0.01 level.
Sensitization	16.443	2	"
Bounce higher than initial TTS.	2.791	2	Not Significant.

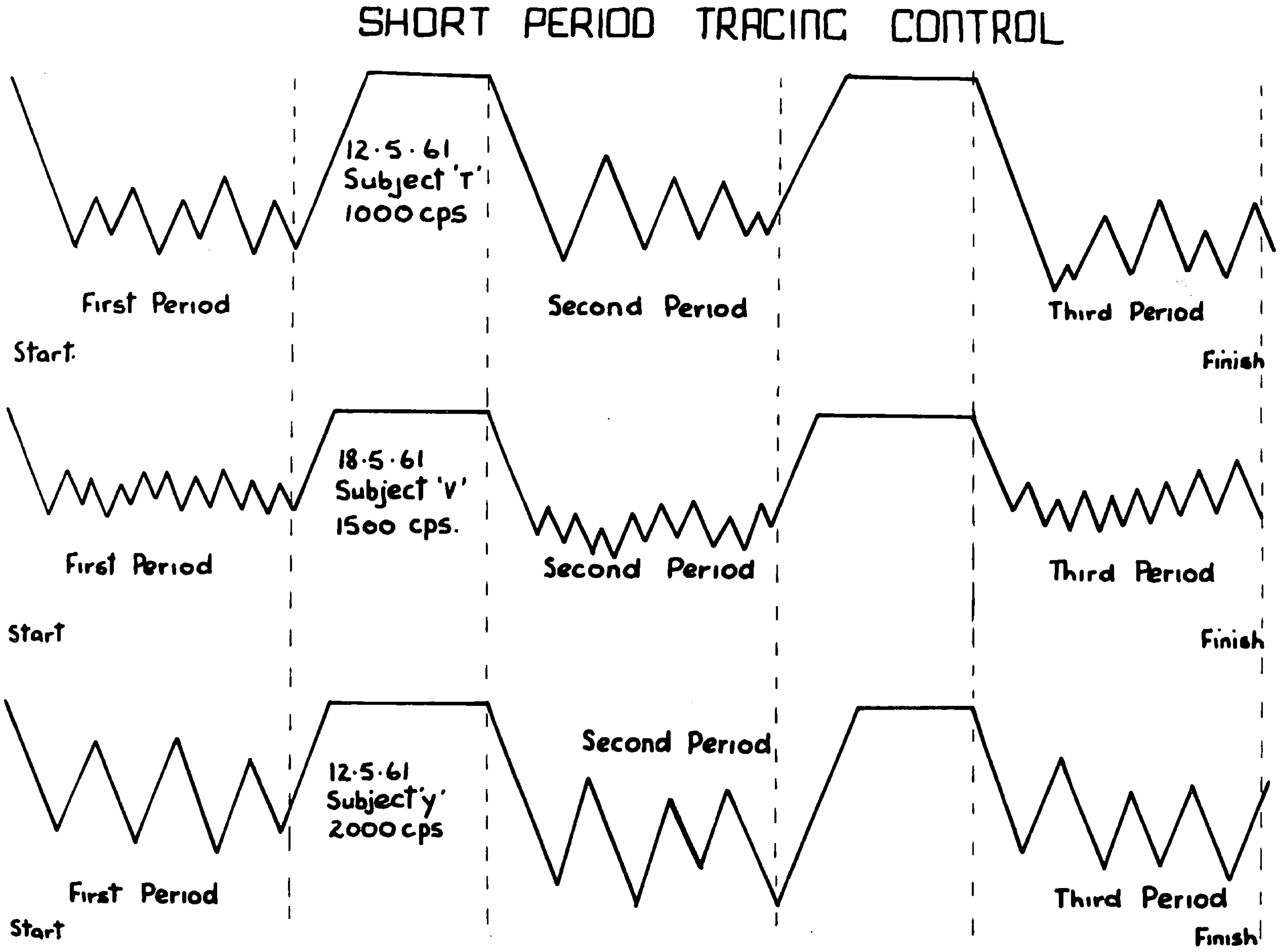


Figure 25: Shows typical tracings obtained when the Békésy technique was used for three minute periods, inter-spaced with two minute rest periods. Time is from left to right (1" to 1.39 mins). Intensity is from top to bottom (1" to 9.09 db.).

175 to 179) to ascertain whether the classification of the recovery curves differed significantly in the two methods. In all cases the number of expected frequencies less than 5 was less than 20 per cent of the total number of expected frequencies. Hence, no combination of categories was required. The results of the whole analysis are summarized in table XXVll. It can be seen from the table that for diphasic recovery and sensitization, the distribution of the results differs significantly with the two methods. Consequently, we must conclude that the way in which the threshold is measured affects the number of results showing diphasic recovery and sensitization.

(d) Békésy tracing for long and short periods.

In view of the relatively large variations in threshold observed when the Békésy method was used to trace the threshold for fifteen minute periods at one frequency, a further control experiment was devised. Instead of tracing continuously the subject was asked to trace for three minutes and he was then allowed to rest for two minutes. This cycle was repeated three times to give a total testing time of fifteen minutes. Figures 25a to 25c are examples of tracings obtained in this manner.

It can be seen from the figures that there is very little cyclical variation over any given three minute sub-period or over the total fifteen minute test period. None of the records showed any of the aperiodic cyclical variations which characterised the periods during which the threshold was traced continuously for fifteen minutes. To investigate the validity of the control experiment in which the stimulus tone was replaced by a period of silence (see page 111), the threshold value for each three minute period was calculated by taking the mean of all the transition points in that period. Differences between successive periods were calculated for each subject. Then the mean and standard deviation of these values were calculated for the four subjects used in the experiment. The mean threshold shift was found to be -0.87 db. and the standard deviation 2.98 db.

Only four subjects were available (see page 62) for the tracing for long and short periods and parametric statistics are not

Table XXV111

Summarizes the t-test applied to test whether there is a significant difference in threshold shift at the beginning and the end of a one and a half to two hour test period.

	(a) Beginning of test period.	(b) End of test period.
Number of Subjects	6	6
Mean	7.8 db.	8.4
Standard Deviation	3.67db.	3.82

Productmoment correlation = 0.86

Standard Error of the difference ($S.E._{MD}$) = 0.53

$$t = \frac{M_1 - M_2 - 0}{S.E._{MD}}$$ (see Garrett, 1958, page 227)

$$= \underline{1.13}$$

t of 1.13 with 11 degrees of freedom is not significant applicable to the data (see page 115). Hence it was decided that it was impracticable to apply a statistical test to this data and the data collected in the control experiment in which the stimulus tone was replaced by silence. However, the two means (-0.87 and -1.39) and the two standard deviations (1.47 and 2.98) are reasonably close to each other.

(e) Control for additive effects of TTS.

TTS was recorded at the beginning and the end of a one and a half to two hour test session, after exposure to an 110 db. tone at stimulus frequencies of 1000, 2000 and 3000 cps. The TTS at each frequency, for each subject and for each period was calculated. Group means for the whole of the experiment were then calculated. The mean TTS for the periods at the beginning of the session was found to be 7.8 db. and for the periods at the end of the period was found to be 8.4 db. The standard deviations of the two sets of scores were found to be 3.67 db. and 3.82 db. respectively. The product moment correlation coefficient between the two sets of scores was calculated and found to be 0.86. It can be seen from the above that there was an increase in mean TTS of 0.6 db. from the beginning to the end of test session.

Since the distribution of TTS is normal (see page 76), a 't'-test, taking account of the correlation, was applied to the data (see Garrett, 1955, pages 226 to 228). The results of this are summarized in table XXVIII. It can be seen from the table that the difference between the two means is not significant. Hence we must conclude that there were no significant additive effects of successive exposures over the duration of the test session.

(f) Test Environment.

The final control experiments consisted of measuring the overall noise level in the test cubicle. No measurements were obtainable on the frequency ranges A and B of the meter. These weight the frequencies in relation to the 40 and 70 phon Fletcher-Munson (1933) equal loudness curves. The minimum intensity measurable on the meter was 24 db. Thus the overall intensity of the sound on these frequencies must

Table XXIX

Overall noise level in the test cubicle as measured by the Dawe Sound Level Meter (Type 1400E, setting C) for three three hour periods at fifteen minute intervals.

	Time of Testing		
	11.30 a.m. to 2.30 p.m.	2.30 p.m. to 5.30 p.m.	8.45 a.m. to 11.45 a.m.
Time from commencement of testing (in minutes)	Meter readings in db. re 0.002 dynes/cm^2		
15	39	34	36
30	36	38	39
45	41	40	42
60	39	33	44
75	46	35	43
90	40	36	41
105	42	37	40
120	34	43	38
135	42	40	38
150	34	35	40
165	38	37	41
180	44	37	42
Mean Noise Level in db. re 0.0002 dynes/cm^2	37	37	40
Standard Deviation in db. re 0.0002 dynes/cm^2	4.61	2.97	2.33

Mean for all three three hour periods = 38 db.

Standard deviation for all three three hour periods = 3.51 db.

Table XXX

Overall noise level in the test cubicle as measured by the Dawe Sound Level Meter (Type 1400E, Setting C) for three fifteen minute periods at one minute intervals.

	Time of Testing		
	11.30 am to 11.45 a.m.	4.00 p.m. to 4.15 p.m.	10.45 a.m. to 11.00 a.m.
Time from commencement of testing (in minutes)	Meter readings in db. re 0.002 dynes/cm^2		
1	39	36	38
2	38	35	34
3	36	37	39
4	42	37	32
5	38	37	33
6	36	36	36
7	36	38	36
8	34	38	38
9	37	41	37
10	37	38	35
11	36	37	40
12	35	39	38
13	38	35	36
14	35	38	36
15	36	37	38
Average	37	37	37
% of raw values within ± 2 db. of average	86%	94%	73%
% of raw values within ± 4 db. of average	93%	100%	93%

have been less than 24 db. On a setting C, the sound level meter equally weights all frequencies between 32 and 8000 cps. The noise level readings obtained during the three hour and the fifteen minute recording periods are given in table XXIX and XXX. It can be seen from table XXIX that on setting C the mean noise level over the three hour periods was 38 db. and the mean standard deviation over the three hour periods was 3.51 db. Table XXX indicates the constancy of the noise level, since in the three recording periods 86%, 93% and 73% of the raw values come within ± 2 db. of the mean and 93%, 100% and 93% of the raw values come within ± 4 db. of the mean.

CHAPTER XI

Summary of the results presented in chapters V111 to X (inclusive)

To refresh the memory of the reader the main results of each of the experiments performed are summarized below :

Experiment.	Results.
(a) Training	A gradual diminution of variability of results.
(b) Stimulus Variables	
(i) Condition 'A'	A linear increase in TTS with stimulus duration. With 110 db. stimulus intensity, the linear increase divides into seperate parts. 70, 90 and early 110 db. increases parallel each other.
(ii) Condition 'B'	No significant increase in TTS as the stimulus intensity is increased from 70 to 95 db. Thereafter, significant increases; the severity of the increase being dependent on the severity of the stimulus conditions.
(iii) Condition 'C'	TTS maximal at 1000, 2000 and 3000 cps or at 1000, 2000 and 4000 cps depending on the severity of the stimulus conditions.
(c) Test Tone Variables	TTS maximal at a frequency half an octave above stimulus frequency. Increased severity of stimulus conditions produces maximal effect at this frequency. Range of frequencies affected relatively constant with stimulus frequencies below 3000 cps.
(d) Recovery from TTS	
(i) Latent Time	Shows a "bounce" type phenomenon at

	1000 and 2000 cps. Latent time is maximal at 4000 cps and minimal at 1000 cps. Increases at 4000 and 8000 cps parallel each other.
(ii) Data from stimulus and test-tone variables	Diphasic recovery is maximal at a 90 db. stimulus intensity and a 2 minute stimulus duration. Sensitization and bounce higher than initial TTS decrease and increase respectively, as the severity of the stimulus conditions increase. Diphasic recovery is maximal at 1000, 2000 and 3000 cps and minimal at 4000 cps. Sensitization is minimal at 1000, 2000, 3000 and 4000 cps. Bounce higher than initial TTS is minimal at 1000, 2000 and 3000 cps and is maximal at 4000 cps. There are individual variations in the incidence of diphasic recovery. Individuals most susceptible to diphasic recovery are least susceptible to sensitization.
(e) Control Experiments	
(i) Stimulus Tone replaced by silence	Mean shift in threshold was -1.39 db. with a standard deviation of 1.47 db.
(ii) Békésy method	Produces aperiodic, cyclical variations in the threshold which are larger than those produced by a modified method of limits.
(iii) Recovery	Phenomenon observed are quantitatively dependent on the method used to measure them.
(iv) Tracing for short periods.	Does not produce aperiodic, cyclical variations in threshold. Mean shifts

	similar to those obtained when stimulus tone replaced by silence.
(v) Additive effects of TTS	Did not significantly effect experimental results.
(vi) Test Environment	Mean noise level was 38 db. on 'C' weighting of sound level meter. Little variation over fifteen minute test periods.

PART 3.

DISCUSSION.

CHAPTER X11

Discussion of results of the experiments studying the stimulus and test tone variables.

(a) Stimulus Tone Variables.

The general conclusion which arises from the results in which the stimulus tone variables were studied is that there is more than one kind of TTS. This suggestion has been made by earlier writers such as Caussé and Chavasse (1947), Hood (1950) and Hirsh and Bilger (1955). However, apart from the discussions on diphasic recovery it seems to have been largely ignored by the majority of workers. Hirsh (1952, pages 177 to 187), for example, discusses the results of Davis, Morgan, Hawkins, Galambos and Smith (1950) and Causse and Chavasse (op.cit.) and of many other studies as a unitary whole. He makes no attempt to sub-divide the data into experiments appertaining to two seperate but related phenomenon. More recently, Ward and his co-workers (see, for example, Ward, Glorig and Sklar, 1959 a and 1959b) make no attempt to emphasize the differentiation between their high intensity TTS and TTS resulting from more moderate exposures. It seems unlikely that they are unaware of the difference, but they do not specifically state this. The results of the three stimulus tone experiments are described in the subsequent sections.

(i) Stimulus Duration

The existence of two TTS phenomena is most strikingly revealed in the experiments on stimulus duration. The change in the slope of the 110 db. line in figure 6 (page 68) and the consistency of this change with individual subjects unequivocally indicates that the short stimulus durations at 110 db. have a different effect than longer stimulus durations at the same intensity. The TTS effects at stimulus intensities of 70 and 90 db. appear to equate with the effects produced by short duration 110 db. stimuli. Hence, the parallelism between the three lines. The effect associated with 70 and 90 db. stimulus intensities and short duration 110 stimuli will be subsequently referred to as fatigue. The effect associated with 110 db. stimuli of long duration will subsequently be referred to as temporary stimulation deafness.

The results showing the existence of a critical stimulus duration are contrary to the results of Hood (op. cit.), who found that no such critical duration existed. There are two possible explanations of this discrepancy. Hood used only a stimulus intensity of 100 db. This intensity is only just above the critical stimulus intensity of 85-95 db. Consequently, we can conclude that Hood's stimulus intensity was very close to the minimal intensity at which temporary stimulation deafness is manifested. The results of this study (see figure 6, page 68) indicate that no critical duration exists at a 90 db. stimulus intensity. Consequently, if a critical duration exists with a 100 db. stimulus intensity, it may be so slight as to be unobservable without highly refined techniques of measurement. Hood also measured his TTS at a latency of 10 seconds. However, the work on diphasic recovery has shown (see pages 29 to 36) that recovery from fatigue can be seperated from recovery from temporary stimulation deafness. The subject recovers from fatigue in approximately the first minute after the cessation of the stimulus tone, whereas recovery from temporary stimulation deafness appears to take longer than one minute. Hood's 10 second latency seems to have allowed fatigue to affect the TTS measurements far more than temporary stimulation deafness. Temporary stimulation deafness will be present at this latency, but we shall see later it produces a much smaller TTS effect than fatigue. Hence, it will only have slight effect on the TTS measurements.

The above hypothesis was tested by a re-analysing of the experimental data. In the re-analysis the mean post-exposure threshold in the first minute and the third minute after exposure were calculated for each subject at the 110 db. stimulus intensity. The mean threshold for the third minute of the post-exposure period was substracted from the mean threshold for the first minute of the post-exposure period. Recovery from temporary stimulation deafness is much slower than recovery from fatigue. Hence it was thought that the corrected threshold for the first minute of the post-exposure period would be largely but not completely representative of fatigue effects. The mean threshold shift in the third minute of the post-exposure period was thought to result from temporary stimulation deafness, since recovery from fatigue is completed within approximately one minute of

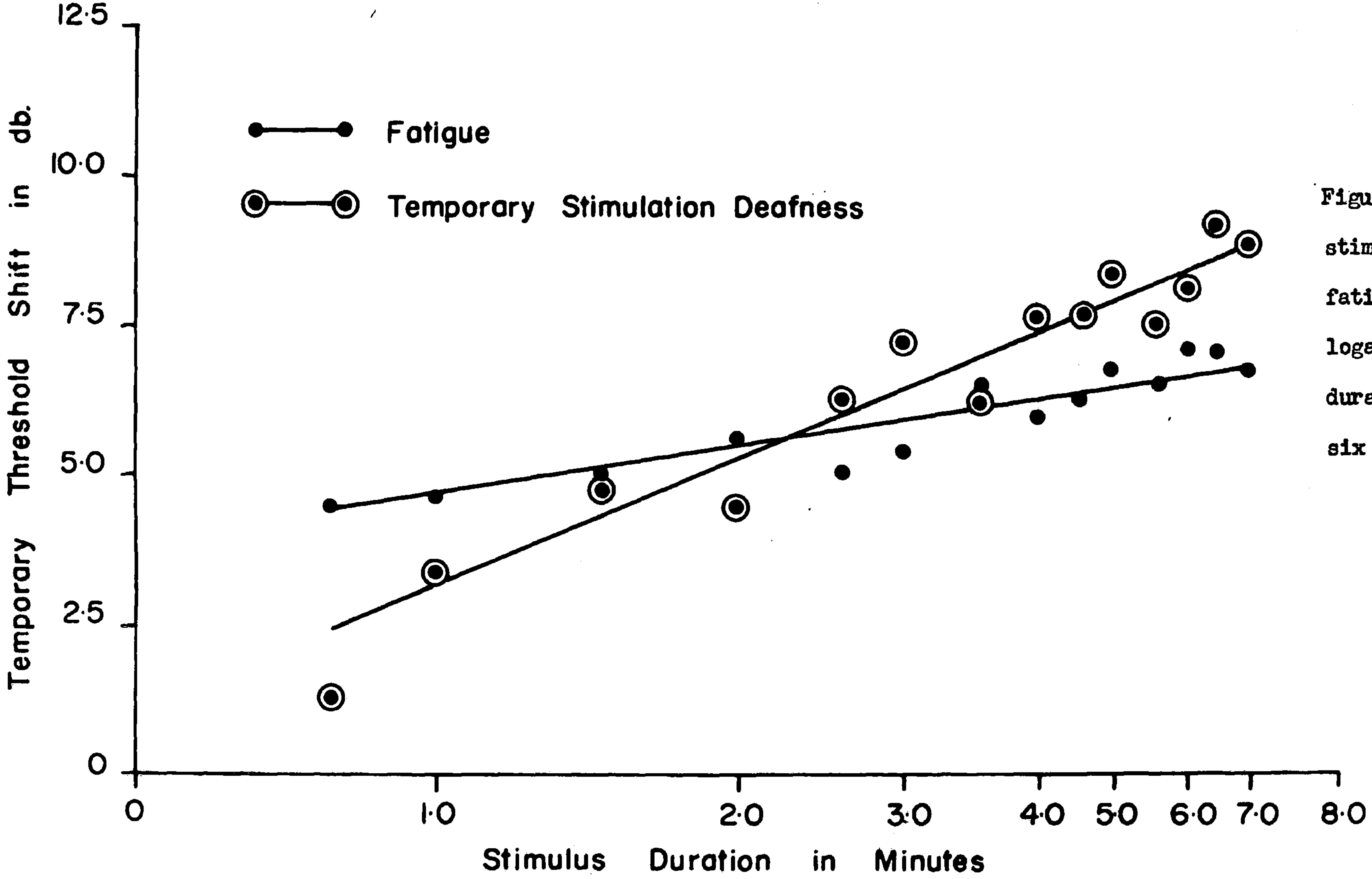


Figure 26: Shows temporary stimulation deafness and fatigue as a function of the logarithm of the stimulus duration. Mean results for six subjects.

the cessation of the stimulus tone. Two measures of TTS were then calculated by substracting from the two post-exposure thresholds the pre-exposure threshold. The means of these two TTS effects were then calculated seperately and plotted as a function of the stimulus duration. The results are shown in figure 26. It can be seen from this figure that both TTS measures show a linear increase in TTS with stimulus duration. However, neither of them independently show the existence of a critical stimulus duration. Instead the two lines cross at a stimulus duration approximately equal to the critical stimulus duration shown in figure 6. Hence we may conclude that showing the existence of a critical stimulus duration is dependent upon allowing both fatigue and temporary stimulation deafness to influence the TTS measures. This was one of the reasons for choosing a post-exposure threshold period of three minutes in the present experiments.

(ii) Stimulus Intensity.

The experiments on the variation of TTS with stimulus intensity confirm the existence of fatigue and temporary stimulation deafness. Intensities below the critical stimulus intensity produce fatigue effects which are independent of the stimulus intensity. Intensities above the critical stimulus intensities produce temporary stimulation deafness effects which increase rapidly as the stimulus intensity is increased.

The critical stimulus intensity is related to the stimulus duration. Figure 8 (page 72) and table 1V (page 75) revealed that it decreases as the stimulus duration is increased. Unfortunately no stimulus durations of less than a minute were used in these experiments. However, it seems likely that because of the existence of a critical stimulus duration, that durations of less than a critical value will produce constant effects over a wide range of stimulus intensities. Similarly we can hypothesise that with stimulus durations of less than the critical duration, the critical stimulus intensity will remain relatively constant. It also seems likely that the converse of the critical stimulus intensity - stimulus duration relationship will apply, i.e. the critical stimulus duration will vary with the degree to which the stimulus intensity

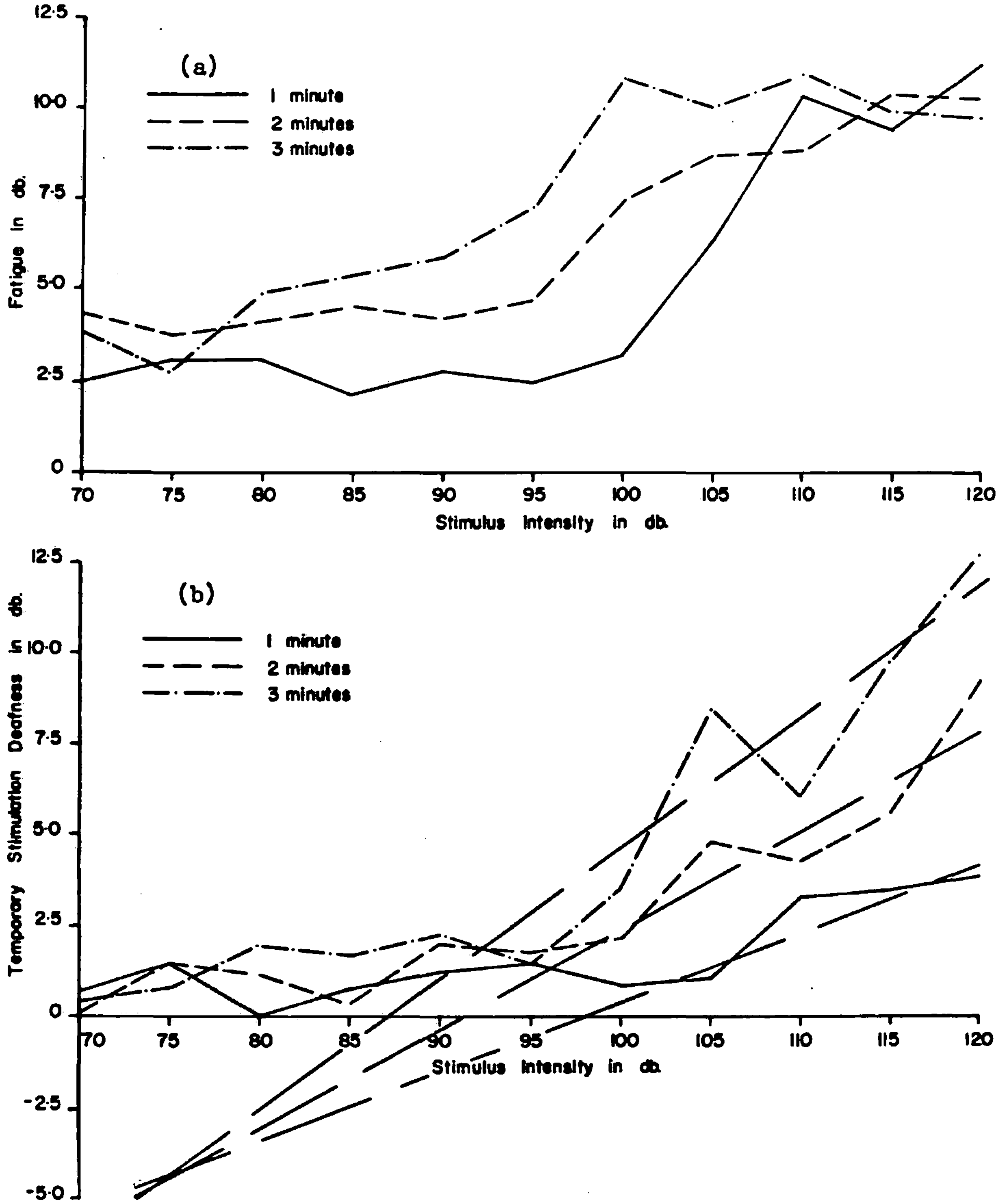


Figure 27: Shows fatigue and temporary stimulation deafness as a function of stimulus intensity. Parameter is stimulus duration. Mean results for six subjects.

used exceeds the critical stimulus intensity. Unfortunately in the experiments on stimulus duration only one stimulus intensity exceeded the critical intensity and consequently it is not possible to test this hypothesis.

The results obtained in these experiments do not agree with those of Ward, Glorig and Sklar (1959a) who found that the increases in TTS above the critical intensity increased linearly with stimulus duration. A comparison of figure 8 with the results of Hood (1950) show that his results are qualitatively similar to those obtained in this study. However, quantitatively Hood obtained much greater increases in TTS with stimulus intensity than the increases shown in figure 8. Subjectively it would appear that the results obtained in this study fall in between those of Ward et al. and Hood. The difference appears to be associated with the way in which TTS is measured or produced, that is with the degree to which fatigue or temporary stimulation deafness predominates in the results. Ward et al. used extremely intense stimuli for extremely long durations. It seems likely that such conditions would produce amounts of temporary stimulation deafness sufficient to obviate any fatigue effects. Hood, as in his experiments on stimulus duration, measured TTS 10 seconds after the cessation of the stimulus tone. We have already seen in the previous section that this allows fatigue to predominate in the measure of TTS. In this study the choice of a TTS measure reflecting both fatigue and temporary stimulation deafness seems to have produced results which have combined the two effects.

To test this hypothesis the data was re-analysed in the same way that the data on stimulus duration was re-analysed. Thus the threshold in the first and third minute of the post-exposure period was calculated for each subject and the latter subtracted from the former. The pre-exposure threshold was subtracted from the corrected threshold for the first minute of post-exposure and from the threshold for the third minute of post exposure. Thus two measures of TTS were obtained and the means of these two TTS effects were calculated separately. Figures 27a and 27b show the two TTS measures plotted as a function of stimulus intensity. Figure 27a initially shows the rapid increases in TTS above the critical intensity which characterized Hood's result. However, at intensities above those used by Hood, the graph changes from acceleration to deceleration. Figure 27b shows the linear increases characterizing the results of Ward et al.

Figure 27a seems to indicate that fatigue increases rapidly at intensities above the critical stimulus intensities and then as the intensity is further increased the rate of increase declines rapidly. This interpretation is contrary to that of Hood's and other writers who suggest that changes in the TTS - intensity relationship, at the critical intensity, reflect only a change from fatigue to temporary stimulation deafness. It would appear from the data presented in figures 27a to 27b that the critical stimulus intensity not only demarcates fatigue and temporary stimulation deafness; but it also represents an intensity at which fatigue begins to increase rapidly. If we assume a neural locus for fatigue then this phenomenon can be explained (see page 173). Whether the critical intensity is the same for these two phenomena is undecided. However, it seems quite possible since further inspection of figures 27a and 27b reveals that the critical intensity for increases in fatigue changes in a similar manner to the critical intensity for the commencement of temporary stimulation deafness. There appears to be an inter⅞relationship between the two phenomena. Consequently fatigue reaches its maximal values at those intensities at which temporary stimulation deafness first makes its appearance.

This suggestion would appear to be relevent when the hazardous effects of noise are being discussed with reference to the results of TTS experiments. However, in experiments such as some of Spieth and Trittipoe (1958b), it is unimportant since they measured TTS five minutes after the cessation of the stimulus tone (see page 16). Fatigue effects will have dissipated by this time. In experiments such as those of Harris (1953) and some of the other experiments of Spieth and Trittipoe (op.cit.), TTS was measured fairly quickly after the cessation of the stimulus duration. Under these conditions it would seem possible that TTS is affected not only by temporary stimulation deafness but also by fatigue. Figures 27a and 27b also suggests that changes in the weighting of stimulus duration and stimulus intensity in setting damage risk criteria (see pages 14 to 17) are dependent upon the relative values of these factors. It can be seen from figure 27a that although the critical intensity varies there is little change in the maximal amount of fatigue. However figure 27b shows that the amount of temporary stimulation deafness produced varies as the critical stimulus intensity changes in association with the stimulus duration.

The divergency between TTS at one minute, two minute and three minute duration was referred to in discussing the results presented in figure 8 (see pages 72 and 78). It can be seen in figure 27b that this divergency is associated with temporary stimulation deafness and not with fatigue. Although it is not apparent in figure 8 (page 72), it is apparent in figure 27b that this divergency represents three straight lines diverging from a common point, with abscissa 74.8 db. It would seem reasonable to state that this point represents the true critical stimulus intensity at which all stimulus durations produce no temporary stimulation deafness. The difficulty with this hypothesis is that it means that a negative amount of TTS is produced at the critical intensity. Ward, Glorig and Sklar (1959b) have explained this by suggesting that the measured threshold does not represent the "true" minimum threshold of the ear. The measured threshold is higher than the "true" threshold because of the presence of internal masking within the ear. They postulate the existence of "sensory elements" which are constantly activated by these internal masking stimuli. They state that, "It is reasonable to suppose that these will be the first elements to be fatigued." They do not justify this statement, but it seems reasonable since :

(i) These elements must be more sensitive to sound stimuli; otherwise all elements would be activated by the internal masking noise.

(ii) If the elements are already firing, they will be already fatigued to some degree and consequently more sensitive to subsequent stimuli.

The main critism of the theory lies in the implication that a special group of cells are involved. It seems more likely that these cells are not a special group but that they are constantly changing. The constitution of the group will depend on the overall state of all of the hair cells at any particular instant in time.

(iii) Stimulus frequency.

The experiments on stimulus frequency again confirm the existence of two kinds of TTS effects. All of the graphs (see figures 9, 10 and 11 on pages 79a, 79b and 79c) of stimulus frequency against TTS show maximal TTS at stimulus frequencies of 1000, 2000 and 3000 cps with stimulus durations of 1 minute, 2 minutes or 3 minutes and with stimulus intensities of 70 db. and 90 db. The graph of stimulus frequency against TTS shows maximal TTS at 1000, 2000, 3000 and 4000 cps with a stimulus duration of 2 and 3 minutes and a stimulus intensity of 110 db. The 1000, 2000 and 3000 maxima are similar to the results obtained by Hood (1950) and the 4000 maximum is similar to that obtained by Davis, Morgan Hawkins, Galambos and Smith, (1950) and by Ward, Glorig and Sklar (1959a). The 1000, 2000 and 3000 cps maxima are probably produced by fatigue since they are present at the lower intensities and durations. The 4000 cps maximum appears to be associated with temporary stimulation deafness, since it is only present at the higher intensities and durations.

The maxima at 1000, 2000 and 3000 cps have been explained by Hood in terms of equilibration and the volleying of the auditory nerve (see page 24). The close similarity between Hood's results and the results of Derbyshire and Davis (1935) on equilibration confirm the validity of this hypothesis (see Hood, op.cit.). However, the results shown in figures 9, 10 and 11 extend the observations of Hood. The results at 70 and 90 db. stimulus intensities and at 1, 2 or 3 minutes stimulus duration and at a 110 db. stimulus intensity and at a stimulus duration of 1 minute are qualitatively similar to those obtained by Hood. At a stimulus intensity of 110 db. and at a stimulus duration of 2 or 3 minutes there is one important difference. Whereas Hood's results and the former results show increasing amounts of TTS with the three critical stimulus frequencies, the latter results do not. There may be some increases but these are very slight. The explanation of this discrepancy seems to be that these stimuli exceed both the critical stimulus intensity and duration. The results of the experiments on stimulus intensity showed that above the critical stimulus intensity the amount of fatigue increases rapidly until a maximum is reached (see figure 27a, page 145). Consequently it would appear that the constant or slightly increasing amount of TTS at the three frequencies is associated with the production of maximal fatigue. Hence, when the stimulus exceeds both the critical stimulus intensity and the critical stimulus duration, the maximum amount of possible fatigue is being produced at all of the equilibration frequencies.

The most probable explanation for this is that fibres, instead of firing in response to the post-exposure test sound early in the relative refractory period, are now firing towards the termination of this period. The nerve fibres cannot, under these conditions, fire any earlier because this would mean firing in the absolute refractory period. Consequently the recovery times available for nerve fibres firing in rotations of three, two or one become equalized. The gradual reductions in the difference between the 1000, 2000 and 3000 cps maxima as the severity of the stimulus conditions is increased, reflect intermediate positions between the extremes of the relative refractory period. Thus the more intense the stimulus, the more prolonged is the relative refractory period in the post-exposure period.

The maximum at a stimulus frequency of 4000 cps confirms the results of Davis et al. (op. cit.) and Ward et al. (op. cit.). However, it can be seen from the results that this maximum occurs only with stimuli which exceed the critical intensity and duration. An important finding is that even when the 4000 cps is present, the maxima at 1000, 2000 and 3000 cps still persist. However, this would appear to result from the inclusion of fatigue in the TTS measure. We have already seen that fatigue effects predominate in the first minute of the post-exposure period. To test this suggestion the post-exposure thresholds were once again calculated in the first and third minute of the test period (see page 143) and measures of fatigue and temporary stimulation deafness calculated. The results of this analysis are summarized in figures 28

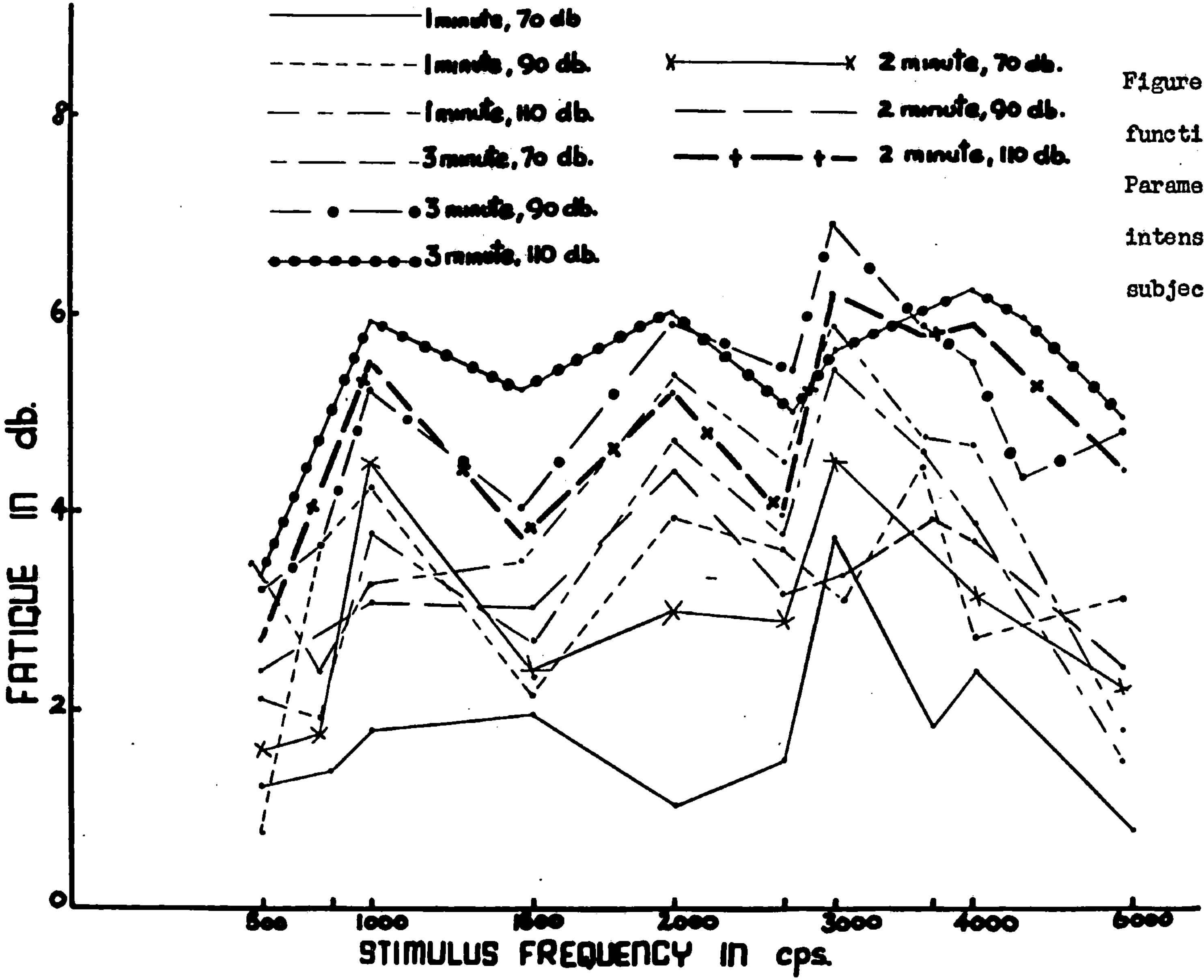


Figure 28: Shows fatigue as a function of the stimulus frequency. Parameter is stimulus duration and intensity. Mean results for six subjects.

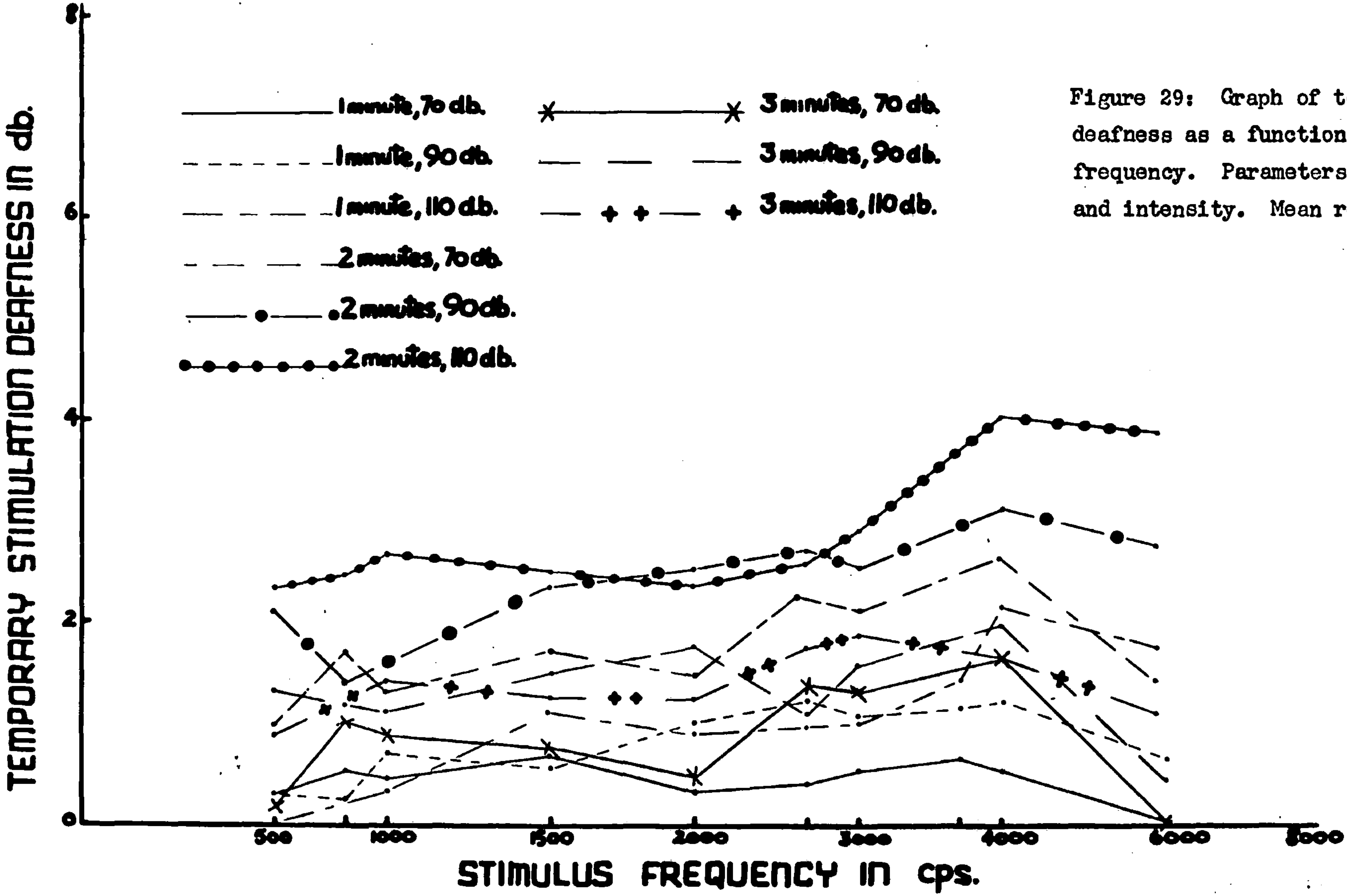


Figure 29: Graph of temporary stimulation deafness as a function of stimulus frequency. Parameters are stimulus duration and intensity. Mean results for six subjects

and 29. It can be seen from figure 28 that the 4000 cps maximum is not so pronounced when the fatigue measure is plotted against stimulus frequency. Figure 29 reveals that the 1000, 2000 and 3000 cps maxima completely disappear when the threshold is recorded only for the third minute of the test period. These results confirm that the 1000, 2000 and 3000 cps maxima are associated with fatigue and the 4000 cps maximum is associated with temporary stimulation deafness.

The 4000 cps maxima probably partially results from the reasonant characteristics of the outer ear. Wiener and Ross (1946) have shown that the closed tube which is formed by the external auditory canal has a natural frequency of vibration of 2000 - 4000 cps and this is maximum at 3000 to 4000 cps. Thus sounds of these frequencies will tend to be amplified in their transmission to the tympanic membrane. As the intensity of the sound is increased the magnitude of these resonance effects will become more and more important. However, this is probably only a minor factor. Hilding (1953) and Kawata (1960) have explained the 4000 cps (c^5) dip in industrial deafness in terms of the anatomical and circulatory structure of the ear respectively. Although the arguments presented by these workers refer to the test tone variations they are applicable to the stimulus tone effects. They will be discussed later (see page 175).

(b) Test Tone Relationships.

The dual nature of TTS again reveals itself in the results of the experiments studying the variation of TTS with the frequency of the test tone. The increases in TTS are greater with the more severe stimulus conditions (see figure 13, page 82). The effect is particularly noticeable with a stimulus intensity of 110 db. The range of test frequencies affected also sub-divides itself into two parts (see table V111, page 84). With frequencies of less than 3000 cps the range of frequencies (in octaves) affected is relatively constant as the test frequency is increased and it never exceeds two octaves. We have already noted that the frequencies of 1000, 2000 and 3000 cps are closely associated with fatigue and equilibration. Above 3000 cps, the range of frequencies (in octaves) affected decreases as the test frequency is

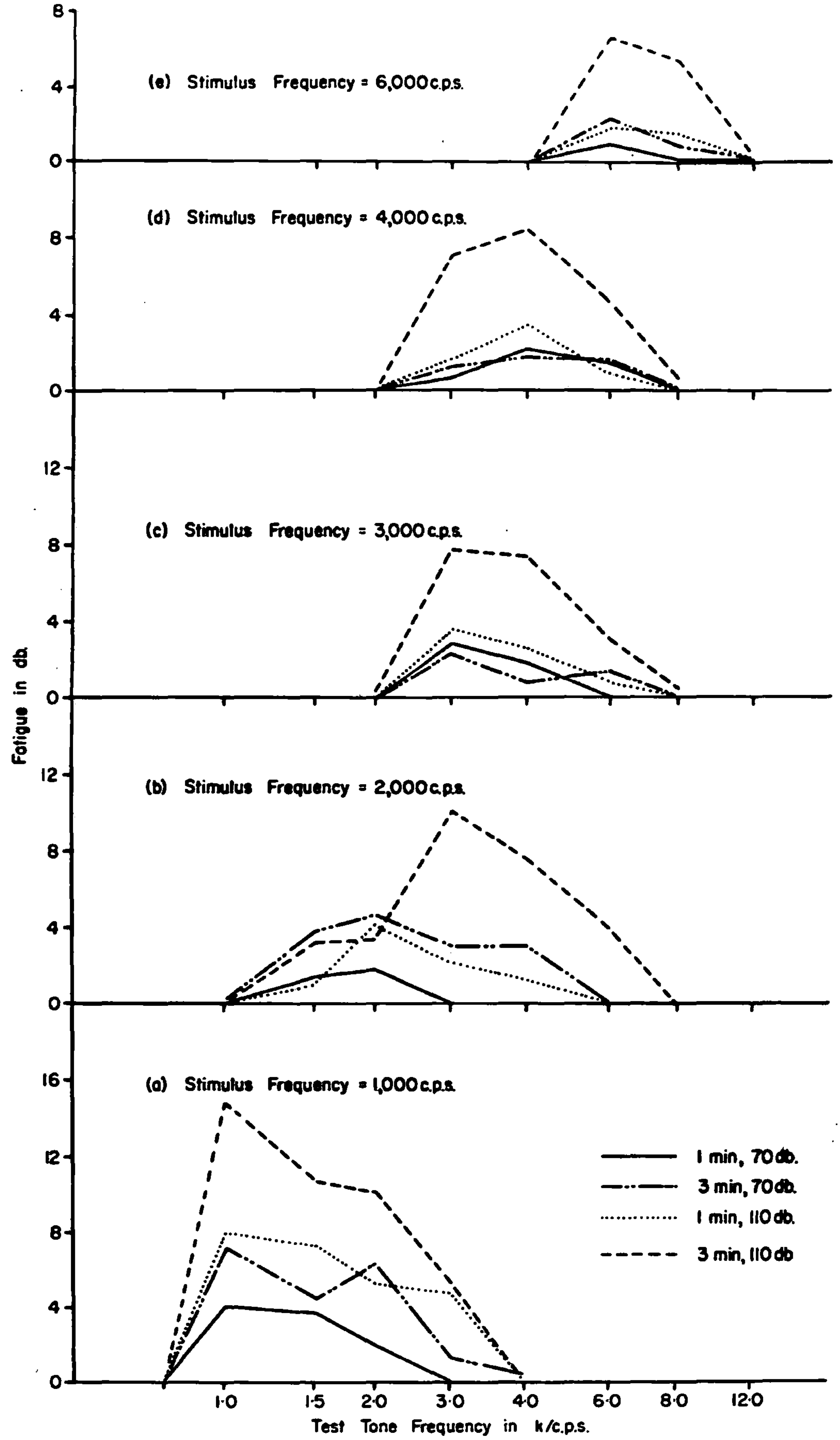


Figure 30: Graph of fatigue as a function of test tone frequency. Parameters are stimulus duration and intensity. Mean results for six subjects.

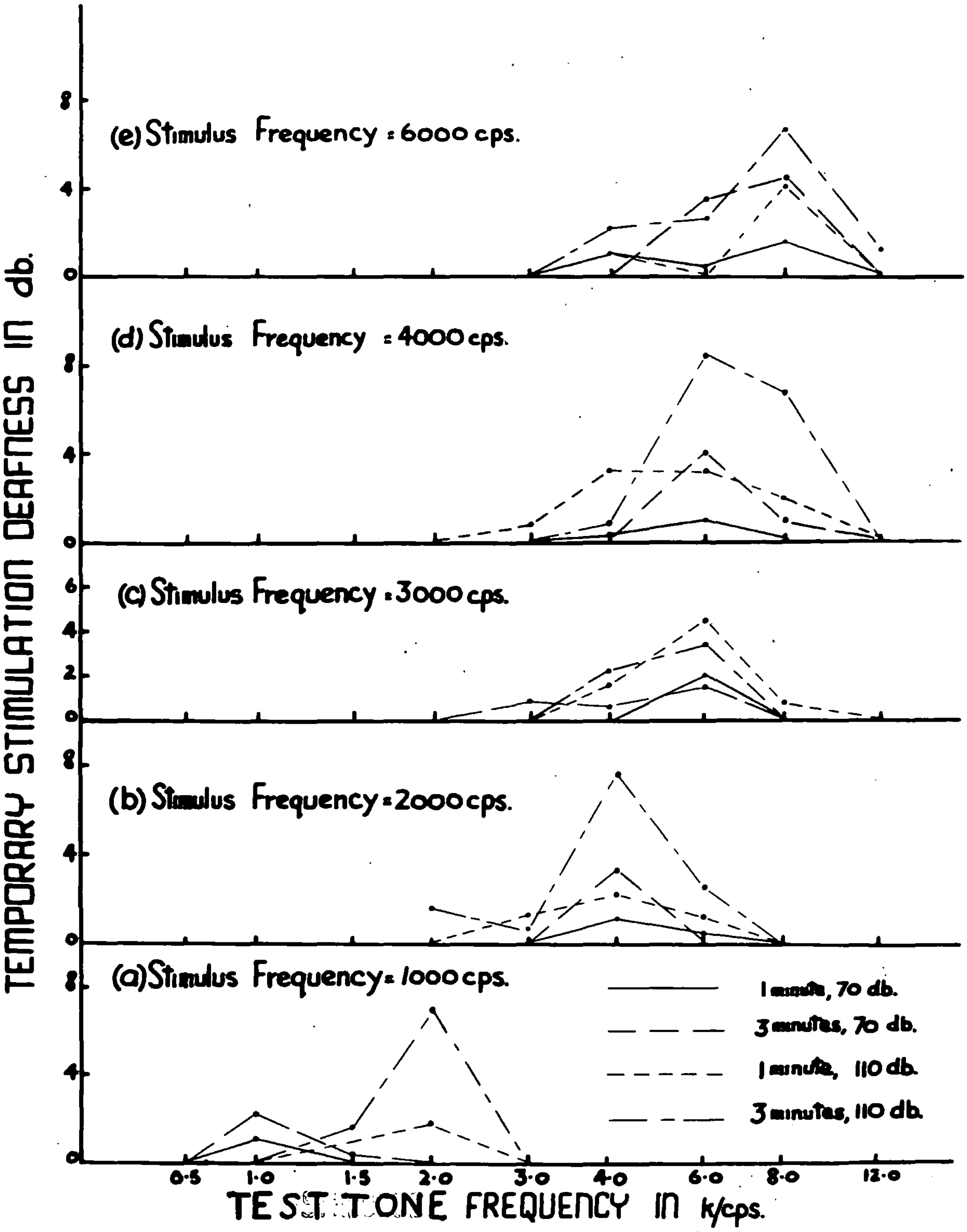


Figure 31: Graph of temporary stimulation deafness as a function of test tone frequency. Parameter is stimulus duration and intensity. Mean results for six subjects.

increased. These frequencies, as we have again noted, are closely associated with temporary stimulation deafness.

The results confirm the observation of Davis, Morgan, Hawkins, Galambos and Smith (1950) that maximal TTS is produced at a test frequency half an octave above the stimulus frequency. However, the results do not confirm the suggestion of Hood (1950) and Hirsh and Bilger (1955) that with low intensity stimuli, TTS is maximal at a test frequency equal to the stimulus frequency. In the results of these experiments the half octave phenomenon is general, except at a stimulus frequency of 2000 cps at an intensity of 70 db. and a stimulus duration of 3 minutes and at a stimulus frequency of 6000 cps at an intensity of 70 db. and a stimulus duration of 3 minutes. In the former case TTS was maximal at a test frequency an octave above the stimulus frequency and in the latter case, TTS was maximal at the stimulus frequency. The fact that these exceptions occur at the extreme ends of the test frequency distribution seems to indicate that the half octave phenomenon is associated with temporary stimulation deafness. It may be that the failure to observe a symmetrical effect results from the influence of temporary stimulation deafness on TTS measures. This influence is associated with the use of a three minute post-exposure period Hood and Hirsh and Bilger measured their TTS shortly after the cessation of the stimulus tone.

The above assumption was tested by again calculating the mean threshold in the first and third minute of the post-exposure period. The threshold for the first minute was corrected by subtracting from this threshold the threshold for the third minute. The pre-exposure thresholds were subtracted from the corrected threshold for the first minute and the threshold for the third minute. This provided measures of fatigue and temporary stimulation deafness respectively. Figures 30a to 30e and figures 31a to 31e show the distribution of these two measures with the test tone frequency. It can be seen from figure 30 that fatigue distributes itself symmetrically about a test frequency equal to the stimulus frequency. It can be seen from figure 31 that temporary stimulation deafness is maximal at a test frequency one octave above the stimulus frequency, with stimulus frequencies of less than 4000 cps. There are five exceptions to these general statements and these are as follows :

(i) With a stimulus frequency of 2000 cps at a stimulus intensity of 110 db. and a stimulus duration of 3 minutes, maximal *fatigue* occurs at a test frequency a half an octave above the stimulus frequency.

(ii) With a stimulus frequency of 4000 cps at a stimulus intensity of ~~110~~ 70 db. and with a stimulus duration of 3 minutes, maximal *fatigue* occurs at a test frequency a half octave above the stimulus frequency.

(iii) With a stimulus frequency of 1000 cps at a stimulus intensity of 70 db. and with a stimulus duration of 1 minute, *temporary stimulation deafness* was maximal at a test frequency equal to the stimulus frequency.

(iv) With a stimulus frequency of 1000 cps. at a stimulus intensity of 70 db. and with a stimulus duration of 3 minutes, *temporary stimulation deafness* was maximal at a test frequency equal to the stimulus frequency.

It is interesting to note that two of the temporary stimulation deafness exceptions occur at 1000 cps. With stimulus frequencies of 4000 cps. and 6000 cps., temporary stimulation deafness is maximal at a test frequency a half an octave above the stimulus frequency or at a test frequency or equal to the stimulus frequency.

The conclusion from these findings is that the half octave phenomenon is under certain conditions an artifact of a combination of fatigue and temporary stimulation deafness effects. The former produces its effect at a test frequency equal to the stimulus frequency. The latter produces its effect at a test frequency one octave above the stimulus frequency, with stimulus frequencies of less than 4000 cps. However, with stimulus frequencies above 4000 cps, temporary stimulation deafness appears to produce its maximal effect at a test frequency a half octave above the stimulus frequency.

CHAPTER X111

Recovery from TTS.

(a) Latent Time.

The experiments on latent time showed that :

(i) At 1000 and 2000 cps, latent time increases with stimulus intensity up to 60 db., decreases with stimulus intensity from 60 to 80 db. and increases with stimulus intensity from 80 to 90 db.

(ii) At 4000 and 8000 cps, there is a gradual negatively accelerating increase in latent time with stimulus intensity.

(iii) Latent time is maximal at 4000 and is minimal at 1000 cps.

(iv) Increases in latent time at 4000 and at 8000 cps, parallel each other.

These results seem to sub-divide into those concerned with 1000 and 2000 cps and those concerned with 4000 and 8000 cps. It may be simply a phenomenon associated with the acoustic reflex (see Wever and Lawrence, 1954). However, this sub-division would seem more likely to be associated with the existence of two TTS effects.

The results offer indirect evidence for the existence of diphasic recovery with stimulus frequencies of 1000 and 2000 cps, since recovery from TTS at these frequencies is slower at stimulus intensities of less than 60 db. than at stimulus intensities of 70, 80 and 90 db. This phenomenon associates itself with the absence of diphasic recovery with stimulus intensities less than 60 db. It confirms the results of Lierle and Reger (1954) who found under certain conditions that recovery is faster at an 80 db. stimulus intensity than at a 20 db. stimulus intensity. The recovery time for 4000 and 8000 cps always increases as the stimulus intensity is increased and it does not show the characteristic inflexion of the 1000 and 2000 cps curves at 60 db. This finding agrees with the results of Hirsh and Ward (1952) and Hirsh and Bilger (1956) who found that stimuli above 4000 cps did not produce diphasic recovery.

Since recovery time exhibits two seperate phases with 1000 and 2000 cps stimuli, it seems logical to assume that at some point in the recovery curves both fatigue and TTS are present. We know from the results on diphasic recovery that only one effect is present below a 60 db. stimulus intensity, since the recovery curve is monophasic. Hence, we can conclude that fatigue, the phenomenon associated with less intense exposures, is the predominating factor at stimulus intensities of less than 60 db. It is unlikely that temporary stimulation deafness alone predominates at the 70, 80 and 90 db. intensities for two reasons. These are :

(i) Temporary stimulation deafness is more closely associated with intensities above the critical stimulus intensity of approximately 85 to 95 db.

(ii) Recovery from temporary stimulation deafness seems to take longer than recovery from fatigue.

Hence we can conclude that the reduced latent times at 70, 80 and 90 db. result from a combination of fatigue and temporary stimulation deafness. The increase in latent time at 90 db. confirms this hypothesis since it is at this intensity that temporary stimulation deafness becomes noticeable.

The importance of this indirect evidence for the existence of diphasic recovery is that without using the Békésy technique, it suggests that recovery is diphasic. Mr. D.E. Broadbent [1] (private communication) has suggested that diphasic recovery might be an artifact of the Békésy technique of threshold measurement. However, the results of Hirsh and Ward (op. cit.) in which they used clicks to measure the threshold, the results of Lierle and Reger (op.cit.) and the results of the above experiments conclusively indicate that this is not the case. Diphasic recovery or associated phenomena exist whether or not we use the Békésy technique to measure the post-exposure threshold.

The maximal latent times occur at 4000 cps and the minimal latent times occur at 1000 cps. This is in accordance with the dual fatigue hypothesis. We have already seen (see pages 150 to 154) that a stimulus frequency of 4000 cps produces maximal temporary stimulation deafness. Thus we would expect maximal temporary stimulation deafness to be produced with the 4000 cps stimulus. Since recovery from temporary stimulation deafness is slower than from fatigue, the 4000 cps maximum would appear to reflect the predominance of this factor at this frequency.

[1] Applied Psychology Unit, Cambridge.

This finding is confirmed to a certain extent by results of earlier studies. If the recovery times of Davis, Morgan, Hawkins, Galambos and Smith (1950), using high intensity stimuli, are compared with those of Hood (1950), using moderate intensity stimuli, it can be seen that the former are longer. Lawrence and Yantis (1957) have shown that recovery time is maximal at a 2000 cps rather than at 1500 cps test stimuli, after exposure to a 1000 cps tone, even though TTS is greater at the 1500 cps frequency. This indicates that the longer recovery times are associated with temporary stimulation deafness which we have already seen (see page 158) is maximal at a frequency an octave above the stimulus frequency.

The parallel increases at 4000 and 8000 cps are not similar to those occuring with stimulus duration (see figure 6, page 68). The latter were associated with fatigue, whereas the former are seen to be associated with temporary stimulation deafness. This effect predominates at 4000 cps and in view of the parallelism we must assume that it manifests itself at 8000 cps. The results of Ward, Glorig and Sklar (1959) are indicative of a similar parallelism. These workers suggest that it is the initial TTS that is the important factor in recovery. This is probably true, but they also tend to force curves obtained with different octave bands stimuli to meet at a common point. They have done this with their data and tended to destroy an inherent parallelism which would appear, in the author's opinion, to fit data just as well.

The recovery time at 4000 and 8000 cps seems to reach a constant value as the higher stimulus intensities are reached (see figure 17). This result is in accordance with the results of Glorig et.al. (op.cit.) who found that recovery time was constant and independent of initial TTS or stimulus intensity. However, the results given in figure extend this finding. It is only true at the higher stimulus intensities. Since Glorig et al. only used intensities above 85 db. they did not obtain the increases in latent time with stimulus intensity which characterize the early part of the 4000 and 8000 line shown in figure 17.

(b) Recovery in stimulus and test tone experiments.

The results obtained in this section must be viewed with some reserve, because of the results obtained in the control experiment in which recovery was measured using a modified method of limits technique. When this data was compared with the data obtained using the Békésy technique, it was found that the proportions of results showing diphasic recovery, sensitization and bounce higher than initial TTS was significantly different with the two methods (see pages 130 to 133). It is unlikely that this difference is produced by mis-classification on the part of the observer, since one would expect such errors to cancel each other out.

However, to check this 15 recovery curves were drawn at random from the 54 curves obtained on recovery using the modified method of limits. Three volunteers[1] were asked to assess whether these showed diphasic recovery, sensitization and bounce higher than the initial TTS after these phenomena had been explained to them. The results of their analysis are shown in table XXXI a, b and c, along with the author's analysis of the same curves. Since the observers can be treated as independent samples, the results shown in each table were treated as a contingency table and subjected to a chi-squared analysis (see Siegel 1956, pages 104 to 111). In part a and part b of the table there are more than 20 per cent of the expected frequency having a cell value of less than 5. Hence it was necessary to combine the monophasic and doubtful and the non-sensitization and doubtful categories in order to overcome this (see Siegel, op.cit., page 110.) However, in part c of the table even when the 'no' and 'doubtful' rows were combined more than 20 per cent of the expected frequencies were less than 5. Hence a chi-square analysis could not be applied to this part of the table. The results of the analysis are given in each part of the table. Since a chi-square of 5.684 or 4.000 is not significant with 3 degrees of

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[1] Undergraduate members of the Department of Psychology, University of Canterbury, Christchurch.

Table XXXI.

Summarizes the judgements of the author and three other observers on 15 curves of recovery from TTS. Note that the monophasic and doubtful and non-sensitization and doubtful columns have been combined in the chi-square analysis (see text).

(a) Diphasic Recovery.

	Observer.				
	Author	A	B	C	Total
Diphasic	7	6	7	7	27
Monophasic	6	6	5	7	24
Doubtful	2	3	3	1	9
Total	15	15	15	15	60

Chi-square = 5.684 (with 3 degrees of freedom)

(b) Sensitization.

	Observer.				
	Author	A	B	C	Total
Sensitization	4	5	6	5	20
No Sensitization	8	7	7	8	30
Doubtful	3	3	2	2	10
Total	15	15	15	15	60

Chi-square = 4.000 (with 3 degrees of freedom)

(c) Bounce higher than initial TTS.

	Observer.				
	Author	A	B	C	Total
Yes	5	4	5	6	20
No	2	1	0	1	4
Doubtful	0	1	2	0	3
Total	7	6	7	7	27

Expected frequencies too small to calculate chi-square.

of freedom, we can conclude that the judges did not differ significantly in the way they classified the curves as showing diphasic recovery or sensitization. This result is not suprising since the phenomena to be judged are objective and do not rely on intangibles. Hence we must conclude that the differences in recovery obtained using the Békésy and the method of limits technique are the result of differences in the method. Hence the results of the analysis of recovery during the stimulus tone and the test tone experimental trials can only be regarded as suggestive, since they are dependent to a certain extent on using the Békésy technique of measurement. The analysis of the total results obtained was shown (see table Xlll, page 98 and table XlV, page 99) to differ significantly from chance; but how much of this difference is an artifact resulting from the use of the Békésy method it is impossible to say.

Part 1 and 2 of table Xlll (page 98) revealed that as the stimulus intensity and duration are increased the proportion of results showing diphasic recovery is maximal at a stimulus intensity of 90 db. and a stimulus duration of 2 minutes (see page 102). This intensity and duration are approximately the critical stimulus intensity and duration. Hence, we must conclude that the presence or absence of diphasic recovery is closely associated with the simultaneous presence of fatigue and temporary stimulation deafness. At 70 db. and 110 db. where fatigue and temporary stimulation deafness predominate respectively, then the presence of diphasic recovery is reduced to a minimum. This result indirectly confirms Jerger's (1956) result that the amount of bounce is maximum at approximately 95db. It is not a direct confirmation since the results of the author simply refer to the number of subjects showing an observable bounce effect. This difference in technique may explain why the author obtained maximum proportion of bounce at a stimulus duration of two minutes; whereas Hughes (1954) obtained maximum amount of bounce at a stimulus duration of three minutes. However, Hughes' result is not in accordance with the general pattern of bounce occuring at the transition points between fatigue and temporary stimulation deafness.

Similarly parts 1 and 2 of table Xlll (see page 102) revealed that the presence of sensitization decreased as the stimulus intensity and duration were increased. This indicates that sensitization is independent of diphasic recovery and confirms the results of Hughes and Rosenblith (1957). If sensitization and diphasic recovery were closely associated, then we would expect that there would be a 90 db. maximum or minimum to correspond to the 90 db. maximum in diphasic recovery. The decrease in sensitization as the severity of the stimulus conditions are increased reveals that it is a fatigue and not a temporary stimulation deafness phenomenon. The more the latter predominates the less observable is sensitization.

Finally parts 1 and 2 of table Xlll (see page 102) revealed that as the stimulus intensity and duration are increased, then the proportion of individual results showing a bounce higher than initial TTS increase. This seems to be incompatable with the first observation that diphasic recovery is associated with the transition from fatigue to temporary stimulation deafness. However, the discrepancy is easily explained if we accept Hirsh and Bilger's (1955) assumption that the second phase of recovery is associated with long term TTS effects, i.e. with temporary stimulation deafness. The results of the experiments on stimulus tone variables (see pages 142to 154) have shown that the increases in temporary stimulation deafness with stimulus duration and intensity increase much more rapidly than the increases in fatigue with the same variables. Thus as the stimulus duration and intensity increase, then the amount of TTS in the latter phase of recovery increases very rapidly compared to the amount of TTS in the first phase of recovery. Hence the probability of bounce exceeding the initial TTS increases.

The fact that bounce can exceed the initial TTS indicates that either there is some interaction between fatigue and temporary stimulation deafness which reduces the initial TTS or that the latter does not reach its maximal value until some time after the cessation of the stimulus tone. The former hypothesis does not seem likely, since an additive rather than a negative interaction seems most reasonable. The second hypothesis is implicit in the dual recovery mechanism postulated by Hirsh and Bilger (1955). It will be discussed later (see page 181). If correct, then it definitely indicates that temporary stimulation deafness is not a neural "adaptation" effect since the latter would be maximal immediately after the cessation of the stimulus tone.

Parts 3 and 4 of table XIII revealed that as the stimulus and test frequencies were increased the proportion of individual results showing diphasic recovery is maximal at 1000, 2000 and 3000 cps and is minimal at 4000 cps (see page 102). Further inspection of the table also reveals that there are less cases at 1000 cps than at 2000 cps and at 2000 cps than at 3000 cps. It would appear that these maxima disprove the hypothesis that diphasic recovery is maximal at the transition between fatigue and temporary stimulation deafness, since as we have already seen, fatigue is maximal at these frequencies. However, it must be remembered that the amount of temporary stimulation deafness is distributed asymmetrically about a stimulus frequency of 4000 cps whereas fatigue at frequencies intermediate between 1000 and 2000 and 2000 and 3000 cps is very slight. Hence it would appear that at these intermediate frequencies, we tend to obtain a monophasic recovery curve representative of recovery from temporary stimulation deafness. The increased proportions at 1000, 2000 and 3000 cps confirm the transition hypothesis since the closer the frequency approaches to the temporary stimulation deafness maximum, the greater the number of results showing diphasic recovery. The 4000 cps minimum offers further evidence for this hypothesis, since at this frequency we have already noted that temporary stimulation deafness is the predominating effect.

Sensitization is seen in parts 3 and 4 of table XIII to show peak minima at 2000 and 3000 cps and possibly 1000 cps and to be minimal at 4000 cps (see page 102). The 1000, 2000 and 3000 cps minima would indicate that sensitization is a neural effect in some way associated with equilibration and the volleying of the auditory nerve. However, the 4000 cps minimum does not support this hypothesis. This discrepancy is probably an artifact produced by temporary stimulation deafness. The relatively high TTS produced at this frequency may obviate any sensitization. This argument cannot be applied to the 1000, 2000 and 3000 cps minima since the high values of TTS at these frequencies are produced by fatigue, which predominates in the period before sensitization is observed.

Observation of parts 3 and 4 of table Xlll also shows that the proportion of individual results showing bounce higher than initial TTS is minimal at 1000, 2000 and 3000 cps and maximal at 4000 cps. The 4000 cps maximum confirms the results of Hirsh and Ward (1952) who found that bounce is maximal at a test frequency of 4000 cps. Hirsh and Ward (1952) also found that bounce was maximal over the range 1000 to 5000 cps, but since they did not concentrate on the equilibration frequencies this finding does not invalidate the 1000, 2000 and 3000 cps minima.

These results are explained by reference to the relative values of fatigue and temporary stimulation deafness. High values of fatigue are obtained at 1000, 2000 and 3000 cps. These tend to raise the value of TTS during the initial stage of recovery and reduce the probability of recovery in the second stage exceeding initial TTS. Similarly at 4000 cps, temporary stimulation deafness predominates. However, since this predominates in the second stage of recovery, it increases the probability of bounce exceeding the initial TTS.

CHAPTER XIV

Individual Variations.

In all of the three experiments on the stimulus tone variables, the majority of the individual variations in the results (see figures 7a to 7f, 8a to 8f and 12; pages 71, 77a and 80a respectively) confirm the dual nature of TTS. In the experiments on the stimulus duration, subject 'C' showed a complete absence of a critical duration. This presumably means that he is highly resistant to temporary stimulation deafness. Since separate mechanisms are postulated for this and fatigue, it seems likely that subjects will vary in susceptibility to the two effects. It is interesting to note that inspection of table 11 (see page 71), for the 110 db. slopes of the TTS-stimulus duration graphs, reveals that subject 'C' is the subject *most susceptible to fatigue*. However, this may be a chance result. All of the other subjects show a dual susceptibility to both fatigue and temporary stimulation deafness. However, the individual variations in the slopes of the lines relating TTS and stimulus duration and in the value of the critical duration, all indicate individual variations in susceptibility to fatigue and temporary stimulation deafness.

The results for subject 'C' in the stimulus intensity experiments confirm this subject's resistance to temporary stimulation deafness effects. Fatigue appears as the predominating factor at all stimulus intensity. ies This subject confirms the results of Spieth and Trittipoe (1958b) who found that some subjects did not have a critical stimulus intensity. If we consider the results for the other subjects, the individual variations in critical intensity are indicative of their varying susceptibility to the two TTS effects. Comparison of figures 7a to 7f and 8a to 8f reveals that those subjects with high critical stimulus durations also tend to have high critical stimulus intensities. Similarly low critical stimulus durations tend to be associated with low critical intensities. This suggests that it is susceptibility to temporary stimulation deafness that decides the critical stimulus duration and intensity, rather than these latter factors determining susceptibility to the former.

In the experiments on stimulus frequency, two subjects have maxima at 1000, 2000, 3000 and 4000 cps with a stimulus duration of 2 minutes at a stimulus intensity of 110 db. These subjects were obviously more susceptible to temporary stimulation deafness than the other subjects. Two other subjects gave maxima at 6000 cps rather than at 4000 cps. This variation would seem to be associated with anatomical variation in the structure of individual ears. Natural frequency of reasonance of the canal, cochlear place relationships and blood circulation must all be subject to individual variations. Presumably these differences are large enough to produce variations the 4000 cps maximum. This finding is confirmed by the work of Keneddy and Carrell (1959) and Rodda, Smith and Wilson (1963). These workers have shown that the 4000 cps dip in occupational deafness is partially a statistical phenomen. Many occupational deafness cases show dips at 6000 and at 3000 cps. Since the 1000, 2000 and 3000 cps maxima are neural effects then they are probably less subject to variation.

One subject in the test tone experiments tended to show maximal TTS at a test frequency equal to the stimulus frequency. This subject may have been resistent to temporary stimulation deafness, since we have noted that this produces its maximal effect at a test frequency an octave above the stimulus frequency. However, this conclusion is only tentative since the results were only partially consistent and the more extreme exposures produced TTS at a test frequency a half octave above the stimulus frequency.

In the experiments on latent time, subject 'D1' showed abnormal increases in recovery time at 8000 cps., a frequency just below his upper frequency limit of hearing. This is most probably associated with the interfering effects of tinnitus, which was experienced by the subject after exposure at this frequency. However, the result indicates the need for further investigation of these frequencies.

The individual results on recovery during the stimulus and test tone experiments indicate that subjects differ widely in their susceptibility to diphasic recovery, sensitization and bounce higher than initial TTS (see table XV11, page 104). It would appear that these variations are associated with susceptibility to fatigue and temporary stimulation deafness. Thus those subjects with the highest proportion of results showing diphasic recovery tend to be those subjects with the highest proportion of results showing bounce higher than initial TTS. In the extreme case, those subjects with very slight susceptibility to temporary stimulation deafness would probably show no diphasic recovery and thus no bounce higher than initial TTS. We can conclude that susceptibility to diphasic recovery and bounce higher than initial TTS is associated with susceptibility to temporary stimulation deafness. The negative association between diphasic recovery and sensitization is not indicative of a common mechanism for the two. Since diphasic recovery seems to be associated with susceptibility to temporary stimulation deafness, high values of the latter will tend to obscure sensitization.

CHAPTER XV.

Mechanisms of fatigue and temporary stimulation deafness.

The consistent duality of the TTS results means that, to a certain extent, fatigue and temporary stimulation deafness must be treated as seperate mechanisms. They may have a common localization in the auditory system and they combine in many cases to produce a joint TTS, but they still represent two distinct phenomena. It would seem likely that the short term fatigue is a neural and/or organ of Corti effect and that the longer lasting temporary stimulation deafness is more closely associated with the anatomical structure of the ear. Temporary stimulation deafness lasts too long to be completely neural in nature. It is proposed to discuss each of these phenomena in turn and then to discuss the interaction between the two.

(a) Fatigue.

The main characteristics of fatigue are as follows :

(i) It increases linearly with the logarithm of the stimulus duration.

(ii) It is maximal at 1000, 2000 and 3000 cps.

(iii) It shows no significant increase with stimulus intensities below approximately 95 db.

(iv) Above a stimulus intensity of 95 db., it increases rapidly to a maximum

(v) It is maximal at a test frequency equal to the stimulus frequency.

(vi) Recovery is almost complete within approximately one minute of the cessation of the stimulus tone.

The linear increase in fatigue with the logarithm of the stimulus duration appears to be purely a function of the temporal course of the changes involved. The log-linear relation occurs in a great many sensory phenomena. For example Bronk (1929) has shown that fatigue of single stretch receptors of the voluntary muscles shows a linear increase with the logarithm of the stimulus duration. There does not seem to be any adequate explanation of the effect but it is presumably associated with the logarithmic scale of sound intensity.

The maxima at 1000, 2000 and 3000 cps are easily explained in terms of equilibration. Following a volley argument, these frequencies are the frequencies at which the fibres fall into alternation. Alternatively it may be that on a place theory the effect is associated with variations in the number of fibres serving different areas of the basilar membrane. The number of fibres per unit length seems to be relatively constant (see Osgood, 1953, page 91). However, the map of Steven, Davis and Lurie (1935) of "pitch" localization and Culler's (1935) map of frequency localization reveal that there is a progressive "crowding" of the frequencies towards the helicotrema. Approximately 62 cps. to 500 cps. are served by the first turn of the cochlea, 1000 cps to 1600 cps. are served by the second turn of the cochlea and so on. Thus there is a progressive reduction in the width of different bands of frequencies served by different areas. Consequently it seems reasonable to suppose that as the stimulus frequency is increased, there will be areas of maximal effect which will be dependent on the width of the "critical band" associated with different frequencies. However, it seems that Hood's is the simpler and more logical explanation, since the above explanation could just as easily fit a progressive increase in fatigue with stimulus frequency.

The failure of fatigue to vary with the stimulus intensity may be related to the spread of impulses to neibouring fibres. This hypothesis would fit both a place and a volley theory, since both can express intensity as a function of the number of fibres firing. At low levels of intensity of stimulation we can assume that there is a large redundancy of fibres for any given stimulus, since alternative fibres must be available to carry the higher sound intensities. Thus when a low level stimulus is applied it will only fatigue those fibres that are used to warry it. As the stimulus intensity is increased, other alternative fibres will be fatigued. A threshold stimulus will activate even less fibres but the fibres activated _will be those initially activated by any other stimulus_. These will have reached a constant amount of fatigue and consequently the observed amount of fatigue will also remain constant.

The above hypothesis will only hold as long as any alternative fibres are available to accomodate any increases in stimulus intensity. Once all possible fibres are firing an increase in the stimulus intensity can have only one effect, that is an increase in the amount of fatigue of those fibres activated by it. Consequently there is an increase in the observed amount of fatigue. This can be explained by assuming an increasing rate of firing of the fibres. This argument would fit in with a place but not with a volley theory of hearing. Once both the number of fibres activated and their rate of firing reaches the maximal level then fatigue cannot increase. Hence, we obtain increases in fatigue above a stimulus intensity of 95 db. and fatigue eventually reaches a maximal level.

The place theories of hearing assume that whatever its intensity, a given stimulus will always produce maximum displacement of the basilar membrane at the same place. Hence, on a place theory the phenomenon of maximal fatigue at a test frequency equal to the stimulus frequency is easily explained. Fatigue will be maximal at the central area of displacement. Hence, it will be maximal at a test frequency which displaces this area, that is at a test frequency equal to the stimulus frequency. Similarly, if we assume that the fibres have a specific order of firing, the phenomenon is easily explained on a volley principle. Those fibres activated by the stimulus will be fatigued and the same fibres will be most susceptible to activation by a test tone of an equal frequency to the stimulus tone. However, it is possible that other non-fatigued fibres will be activated by the test tone. In this case the argument would not hold.

It must be remembered that the amount and duration of fatigue as observed at a psycho-physical level is only indicative of the amount and duration of fatigue at a cochlear level. Thus although psycho-physical fatigue does not last for much more than a minute, it is quite probable that there remains residual cochlear fatigue which is not observable by conventional psycho-physical techniques. However, the fact that recovery is relatively quick indicates that it is localized in a neural mechanism. The localization can only be hypothesised but in view of earlier work, it may be in the hair cells of the organ of Corti. It is probably bio-chemical in nature and it is possibly associated with the production of the cochlear microphonic by a "piezo-electric" type effect (see Wever, 1949, pages 147 to 154). Meyer (1954) has suggested that it may be associated with bruising of the phragma but this will be discussed later (see page 178).

(b) Temporary Stimulation Deafness.

The main characteristics of temporary stimulation deafness are as follows :

(i) It increases linearly with the logarithmn of the stimulus duration.

(ii) It is maximal at a stimulus frequency of 4000 cps.

(iii) The lines associated with different duration parameters provide a family of curves in which temporary stimulation deafness increases linearly with stimulus duration. These lines stem from a common point with co-ordinates 72.8 db, -4.8 db. for stimulus intensity and temporary stimulation deafness respectively.

(iv) It is maximal at a test frequency an octave above the stimulus frequency, except with stimulus frequencies of 4000 and 6000 cps.

(v) Recovery time from temporary stimulation deafness can exceed one minute, depending upon the severity of the stimulus conditions.

The work on acoustic trauma in guinea pigs and other animals (see for example Eldredge and Covell, 1958) has definitely associated stimulation deafness with displacement and disruption of the hair cells of the organ of Corti. Because temporary stimulation deafness is an effect associated with intense exposures and because of its great similarity to stimulation deafness, it seems that it is also most probably associated with some temporary or unobservable impairment of the functioning of the hair cells. Hence, any explanation of its characteristics will be in terms of the anatomical characteristics of the ear.

The linear relationship between temporary stimulation deafness and the logarithmn of the stimulus duration is, as in the case of fatigue, a purely temporal function of the increases in sound exposure. There is once again no satisfactory explanation of the phenomenon. The whole problem might be associated with the storing of potential energy within the basilar membrane. Equations are available (see for example Rayleigh, 1894, Vol. 1, p. 91-129 for classical work on this topic) for calculating this in fairly simple structures such as vibrating strings. We can assume that the amount of stored potential energy is dependent upon the stimulus duration, if so, it is quite conceivable that with the other stimulus variables kept constant, the destructive effects of the stimulus would bear a logarithmic relationship to the stimulus duration. Such a theory would also predict that there would be a limit to the linearity. The potential energy cannot go on increasing indefinitely but it must reach a maximal value.

The maximum associated with the 4000 cps stimulus frequency has already been discussed briefly (see page 154). Hilding (1953) has considered the flow of sound forces through the cochlear and concluded that they result in an area of high pressure at a point 6 to 8 mm. from the beginning of the first turn of the cochlear. This he considers results in the 4000 cps dip associated with industrial deafness. The reverse process would also apply. A stimulus tone of 4000 cps will produce an optimum effect, since the forces generated are already going to affect that region of the membrane. The funneling of sound hypothesised by Hilding will merely increase the magnitude of the forces generated. Kawata (1960) found that there was a remarkable ischaemia particularly in the basal coil of the cochlea. He concluded that "it may be said that an individual with a lively acoustic tympanic muscle reflex will have an extremely clear C^5 dip and that a vigourous vasomotoric[1] reaction in the cochlear blood vessel may also be aroused in him." Once again the reverse argument holds and the basal area will be predisposed to show the maximal shift.

Kawata argues that Hilding's and other similar explanations (see

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[1] Kawata's term.

Onchi, 1951 and Ruedi and Furrer, 1948) cannot be correct, since the C^5 dip is also found is some cases of perceptive deafness due to alcohol poisoning and in some cases of head trauma. However, he appears to be mixing cause and effect. The manifestation of acoustic trauma within the cochlea may be vasomotor, but something must cause these vasomotor effects and be responsible for them occuring at the 4000 cps region of the basilar membrane. In the case of a C^5 dip resulting from noise exposure, it seems reasonable that an explanation similar to that of Hilding will eventually answer the problem.

The linear increases in temporary stimulation deafness with stimulus intensity are more difficult to explain than the increase in fatigue with stimulus intensities above 95 db. It appears to be associated with the forces to which the response mechanism is subjected, that is to the logarithmic scale of sound intensity. It may be that the relationship is logarithmically linear with respect to the absolute stimulus energy. However, since we measure stimulus intensity on a logarithmic scale, the result of this would be logarithmically linear relationship with stimulus intensity. Another important factor will be the extent of impairment of the hair cells. Stimulation deafness studies could provide information on this possibility. However, the studies up to the present time have not provided sufficiently accurate data about the total area of damage. Hence we are unable to assess any relationship between this and the intensity of stimulation, although the above considerations would predict that it would be some simple monotonically increasing function.

With a variety of stimulus durations, it was found that the linear increases in temporary stimulation deafness, with increased stimulus intensity, originated from a common point. This common point had a negative ordinate (-4.8 db., see figure 27b and page 149), that is a negative amount of TTS. We have already suggested that this negative value results from the presence of "sensory elements" which are constantly activated by internal masking stimuli (see page 149). In accordance with the suggestions made above, these sensory elements could be the hair cells of the organ of Corti. The existence of a resting D.C. potential in auditory nerve transmission (see Ruch and Fulton, 1960, pages

398 to 399) supports this suggestion. It is clear that some elements may be activated in the absence of an externally imposed stimulus. This is in accordance with the above suggestion.

Temporary stimulation deafness is maximal at a test frequency an octave above the stimulus frequency. This is not in accordance with the hypothesis of Meyer (op.cit.). He suggests that there are two effects which will be discussed more fully later (see page 178). One of these he refers to as fatigue and states that it is symetrically distributed about a test tone of 4000 cps. The other he calls "bruising of the phragma" and states that it increases with the test frequency. D.E. Broadbent[1] has suggested in private communication that the basilar membrane may "whip" with high levels of stimulation. If this is the case then it is quite conceivable that this "whipping" may occur in the region roughly an octave above the stimulus frequency. This theory could also explain the irregularities in the results for the test tone experiments at a stimulus frequency of 1000 cps. This frequency is represented towards the end of the basilar membrane. In this case there may be an insufficient length of the membrane lying beyond the 1000 cps. localization for whipping to take place. Similarly, the discrepancies at 4000 and 6000 cps may be caused by the position of representation on the membrane. These frequencies are located towards the basal end. Consequently the fixing of the membrane at this end, may tend to reduce the distance between the point of maximal vibration and the area of whipping.

Finally, recovery from temporary stimulation deafness takes much longer than recovery from fatigue. This suggests that two effects can be separated from each other and that they involve different mechanisms. The time for recovery from temporary stimulation deafness is sufficient to allow the effect to be bio-chemical in nature, although long recovery times do not specifically indicate a bio-chemical effect. Alternatively, the effect may be associated with deformation of the crystalline structure of the hair cells. Whatever the mechanism, the recovery is complete at a psycho-physical level; although this does not mean that slight unobserved

[1] Applied Psychology Unit, Cambridge.

damage might not remain at a cellular level.

(c) Fatigue and Temporary Stimulation Deafness.

In most cases fatigue and temporary stimulation deafness can be separated very clearly in the experimental data. However, there are two cases when it is necessary to consider specifically the interelationship between them. These are :

(i) The half-octave phenomenon in which TTS, recorded with a three minute post-exposure period, occurs at a test frequency a half octave above the stimulus frequency.

(ii) The temporal course of recovery from TTS.

In both of these cases the observed phenomena may not be dependent upon fatigue or temporary stimulation deafness alone, but on an interaction between the two effects.

To explain the half octave phenomenon, Meyer (op.cit.) has postulated a combination of two effects. These are a "bruising" of the basilar membrane which increases monotonically with the stimulus frequency and a "fatigue" effect which is distributed symmetrically about the stimulus frequency. These are illustrated in figures 32a and 32b. Figure 32c shows how a simple additive combination of the two will produce maximal TTS at a test frequency a half octave above the stimulus frequency. However, we can disregard this hypothesis, since the distribution of the two types of TTS does not fit in with Meyer's postulated effects.

The distributions of fatigue and temporary stimulation deafness around test frequencies equal to the stimulus frequency and a test frequency of 4000 cps respectively, could just as easily result in a half octave effect. Figures 33a and 33b represent theoretical distributions of fatigue and temporary stimulation deafness. When additively combined in figure 33c, they produce a half octave phenomenon. If the differences between the two were made large enough, this diagramatic effect would be destroyed. This presumably does not happen in the experimental situation. However, this hypothesis does not appear to fully explain the phenomenon. Temporary stimulation deafness may be maximal at a test frequency a half octave above the stimulus frequency with stimulus frequencies of 4000 and 6000 cps. Under these conditions, it

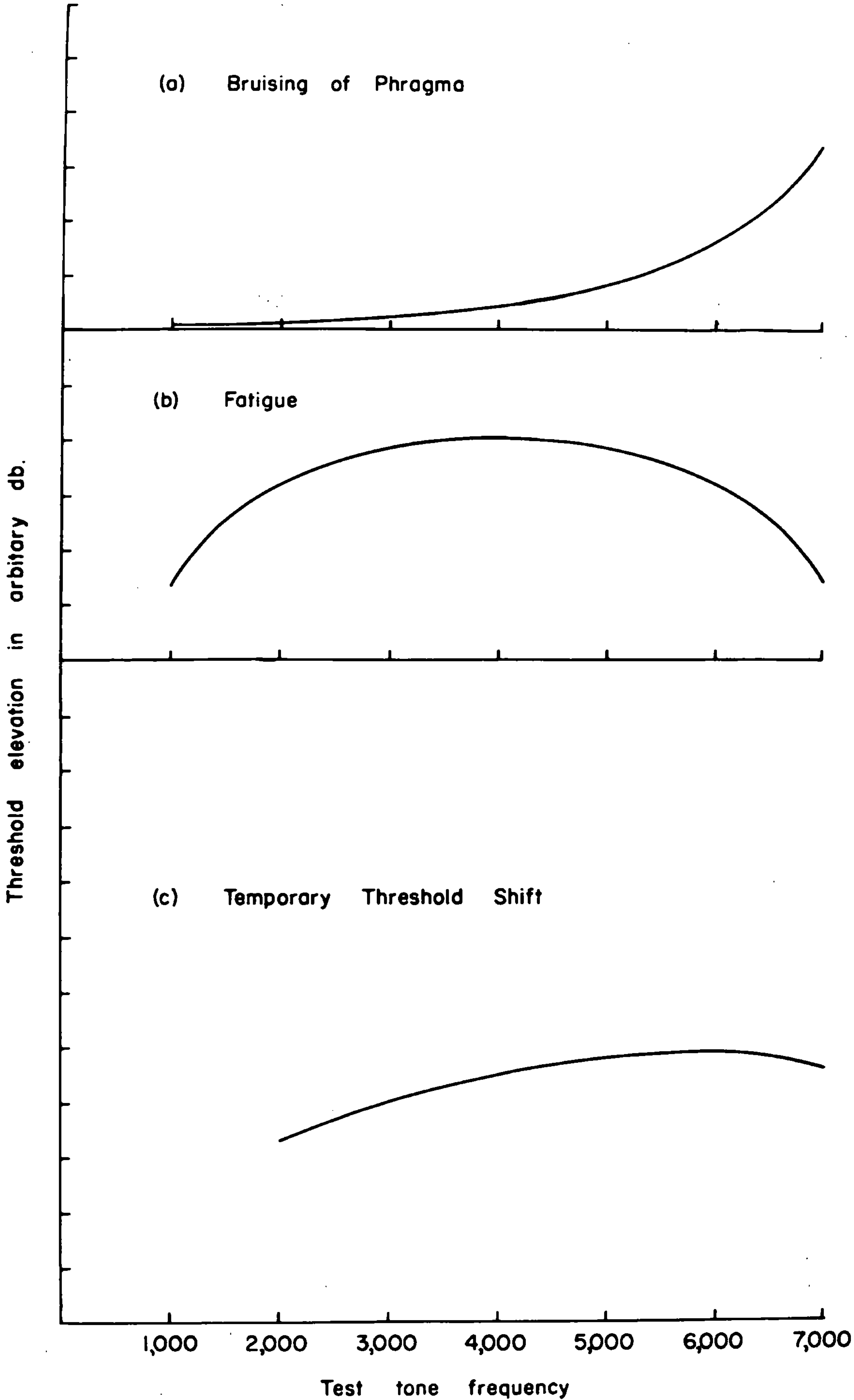

Figure 32: Illustrates Meyer's (1954) explanation of the half octave phenomenon in TTS. Bruising and fatigue combine to produce maximal TTS at a test frequency a half octave above the 4000 cps stimulus frequency.

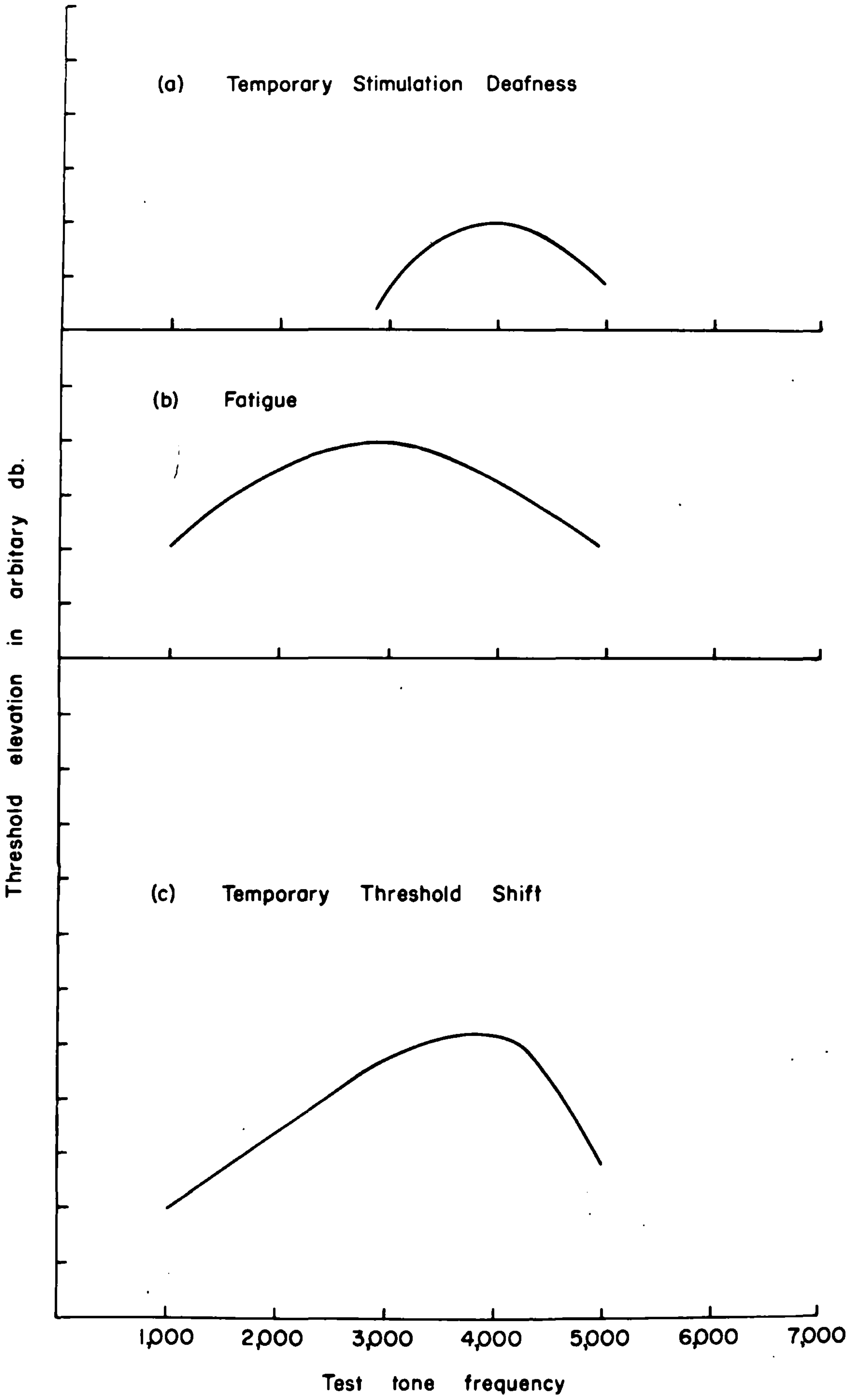

Figure 33: Illustrates the combination of fatigue and temporary stimulation deafness to produce maximal TTS at a test frequency a half octave above the 3000 cps stimulus frequency.

would seem the half octave phenomenon does not result from an additive combination of fatigue and temporary stimulation deafness. It is a maximum associated with the latter effect.

Hirsh and Bilger (1955) explained diphasic recovery as the result of an additive combination of two TTS effects. They suggested a possible neural (R-1) and a possible bio-chemical effect (R-2). R-1 they suggested is completed in one minute and is independent of stimulus intensity and R-2 is slow and is "clearly dependent on the stimulus intensity." The author (see Rodda, 1962) has criticised Hirsh and Bilger's formulation, since at the time of writing there was no evidence of an association between diphasic recovery and the equilibration frequencies. He has postulated (see Rodda, 1960) a theory based on facilitatory and inhibitory effects within the cochlear. This theory utilizes the concept of organ of Corti "fatigue patterns" (see Gardner, 1947). These fatigue patterns represent a residual, decaying pattern of excitation after the cessation of a stimulus tone. Depending on the inter-relationship between the pattern of test tone stimulation and the fatigue pattern, there may be facilitation or inhibition of neural impulses and consequently the decay of the fatigue pattern will, if it is initially large enough, produce a period of facilitation followed by a period of inhibition.

The original criticism of Hirsh and Bilger's theory no longer holds. The results of the experiments on recovery have shown conclusively that there is a close association between the presence or absence of diphasic recovery and the equilibration frequencies. However, Hirsh and Bilger's theory can still be criticized. If two independent recovery processes exist, then it is still difficult to conceive of them producing diphasic recovery. It seems more likely that they would combine to produce a monotonic negatively accelerating recovery curve. It is also difficult to fit the equilibration effects into the author's theory. The difficulties of both theories can be obviated if we postulate, instead of two separate recovery process, two independent TTS effects. Each of these would have its own recovery process; but the combination of the two processes would result in facilitatory and inhibitory effects as postulated by the author. The advantage of such a theory is that it also explains the sensitization effects. These are merely a function of the amount of facilitation present. Hirsh and Bilger have great difficulty in explaining these effects and merely state that the "structure in which R-1 is found is rendered more sensitive than it was before the exposure".

CHAPTER XVI

Controls for External Conditions.

Two control experiments involved periods of silence or non-tracing interspaced between successive periods of Békésy tracing. These gave mean shifts of -1.39 db. and -0.87 db. between the thresholds recorded in successive tracing periods (see page 111 and pages 133 to 135). The smallness of these changes, when compared with the shifts resulting from exposure to a stimulus tone, indicate that TTS results from the introduction of the stimulus tone and is not merely the result of chance fluctuations in the threshold measurements. Of the 271 experimental means obtained in the experiments studying the stimulus and test tone variables (see figures 6, 8, 9 to 11 and 13, pages 68, 72a, 79a, 79b, 79c and 82 respectively), a total of 89 lie within 2.58 σ of the mean shift of -1.39 shown in the first control experiment. Similarly, a total of 126 out of the 271 experimental means lie within 2.58σ of the mean shift of -0.87 shown in the fourth control experiment. At first sight, these numbers may seem rather high. However, the majority of the means involved tend to be associated with the minimum severity of stimulus conditions (70 db. for one minute) or to occur at the extremes of the test tone distribution. Consequently their effect, if any, will only be serious under these conditions.

It would be argued that negative shift in the control experiments reflects over-cautiousness on the part of the subject in the earlier test period. Alternatively it may reflect a facilitatory effect arising from the period of silence or non-tracing. The mechanisms of such a facilitatory effect are difficult to understand. However, evidence for this suggestion comes from work of Özbaydar (1961) who has shown that auditory threshold are lower in light than in darkness. He explains this phenomenon as being due to an increased level of cortical arousal.

The effect could be explained in terms of Broadbent's filter theory and the novelty of stimuli. Broadbent's (1957 and 1958) theory assumes a limited perceptual capacity in the human organism.

Consequently he stresses the need for the performance of some selective operation on all sensory inputs mediated within the organism. Thus the organism "chooses" to respond to certain stimuli and to neglect others. In so doing, it avoids a "jamming" of sensory inputs and a resulting complete inability to respond. A basic assumption in the theory is that an unchanging stimulus situation is associated with a "switching" to other channels of sensory input, particularly if such channels provide a "novelty" of sensory input. Broadbent (1958, page 98) has stated that "novel stimuli themselves receive adequate response and so seem distracting rather than paralysing." He explains the detrimental effects of noise on efficiency and the annoyance effects of noise in terms of this distracting effect (see Broadbent, 1958, chapter 5).

During the periods of silence or non-tracing in the control experiments,there is very little or only a continuous low level auditory input. This continuity of a constant low level sensory input would result in a neglect of the auditory channel and a concentration on other sensory channels. Consequently at the commencement of testing of the post-exposure threshold, the sound is a "novel" stimulus. As such it receives more attention than other sensory inputs and is perceived more easily. The detrimental distracting effects of the nevel stimulus will be obviated for two reasons :

(i) The sound is at a low intensity.

(ii) The subject is warned to expect it by means of the signal light.

The result of the orientation towards auditory information and the increase in perceptual ability, is a lowering of the threshold. Although there is little evidence for the suggestion, it seems likely that a mechanism of this nature could be mediated through the activity of the RAS.

A prediction of the theory is that as the test period progresses, the amount of facilitation will decrease. The reason for this is that as the test period is prolonged, then the tendency will be to "switch" for increasingly longer periods to other sensory channels. To test this suggestion, the mean thresholds in the first, second and third minute of the period immediately following a period of silence or non-tracing were calculated separately for each of the control experiments. These values were substracted from the mean threshold immediately preceding the period of silence or non-tracing. This provided an assessment of the amount of facilitation in each period. In the first control experiment the mean differences between the pre-silence and post-silence thresholds in the first, second and third minute following silence were found to be -2.64, -0.98 and -0.59 db. respectively. In the fourth control experiment the mean differences between the pre-non-tracing and post-non-tracing thresholds in the first, second and third minute following silence were found to be -1.88, +0.17 and -0.92 db. respectively. In calculating these means, the second three minute tracing period was used as the pre-non-tracing period for the third three minute tracing period. It can be seen from the results that there is a progressive reduction in the amount of facilitation as the test period progresses; although in the second control experiment, there is no facilitation in the second minute of the test period. This latter result is probably caused by chance errors.

The larger amount of facilitation in the first control experiment offers further tentative support for the theory, despite the smallness of the difference between this and the amount of facilitation in the second control experiment (see page 133). In the fourth control experiment the subject traced his threshold for three minutes and then rested for two minutes. This cycle was repeated three times to give a fifteen minute test period. It can be seen that only the first of the three minute tracing periods was not preceeded by a period of non-tracing. The second three minute tracing period provided the pre-non-tracing threshold for the final three minute tracing period. However, this period had itself been preceeded by a non-tracing period and must have been affected by the facilitatory phenomenon. This would reduce the amount of facilitation recorded in the final three minute

TABLE XXX11

Summary of the t-test used to test the significance of the difference between the mean amount of facilitation between successive three minute test periods (A) and between the first and second and the first and third three minute periods (B) in the control experiment studying Békésy tracing for short periods.

	A	B
No. of subjects	4	4
Mean Shift	-0.87 db.	-1.86 db.
Standard Deviation	1.98 db.	2.32 db.

$r_{ab} = 0.74$

Standard Error of the difference ($S.E._{D.}$) = 2.15

$$t = \frac{M_b - M_a - 0}{S.E._{D.}}$$ (see Garrett, 1958, p. 223-224)

$= \underline{0.460}$

A t of 0.460 with 3 degrees of freedom is not significant.

tracing period. Consequently, the lowered amount of facilitation recorded in the second control experiment could result from the facilitation itself.

To check the above suggestion the mean difference in thresholds between the first and second and the first and third three minute test periods was calculated. The standard deviation was also recorded. The mean was -1.86 db. and the standard deviation -2.32 db. The product-moment correlation between these results and the results obtained taking successive three minute periods was 0.74. The significance of the difference between the above threshold change and the threshold change of -0.87 db. obtained by taking successive three minute periods, was tested using a t-test (see Garrett, 1958, pages 226 to 228). The results of this calculation are summarized in table XXXll. It can be seen from the table that the difference is not significant. However, it is suggestively in the right direction.

Additive effects of TTS were controlled for in the fifth control experiment (see page 135). This showed that there was a mean increase of 0.6 db. in TTS produced, by 1000, 2000 and 3000 cps stimulus tones at an intensity 110 db., at the beginning and the end of a test session. This increase was not significant and consequently we can assume that there were no significant additive effects and that the recovery period of 15 minutes was adequate.

The sixth control experimènt recorded the mean noise level in the test cubicle over three hour periods and over fifteen minute periods. The mean noise level on the 'C' weighting of the sound level meter was 38 db. in the three hour test periods (see pages 135 to 138). A frequency analysis of the noise was not undertaken since the appropriate equipment was not available. However, the mean of 38 db. is much less than any of the levels suggested by Glorig (1958, page 132), as permissable ambient noise levels in an industrial test situation. Even if we assumed that all of the noise was concentrated in any one octave band, a level of 38 db. is still below Glorig's standards which range from 40 db. for the band 300 - 600 cps through to 67 db. for the band 4800 - 9600 cps, with a mean of 50.4 db. Hence we can confidently state that the noise level in the test cubicle was well below the levels suggested by Glorig. However, these latter values are too high for research work and it is fortunate that the overall noise level is "much less" than the values suggested by Glorig. Another factor to be borne in mind is that the subject was wearing an earphone on the test ear. This would provide further attenuation of extraneous noise.

Reference to the data of Hawkins and Stevens (1950) on the masking of pure tones by white noise indicates that white noise of an overall intensity of 38 db. would elevate the threshold at 1000 cps by not more than 10 db. However, this value is only given as an indication, since we have no information regarding the frequency and intensity spectrums of the noise in the test cubicle. The amount of masking is also dependent on the value of the unmasked threshold, that is upon the intensity of the stimulus. It is impossible to correct threshold measurements, for ambient noise masking because as Glorig (1958, page 75) points out "as hearing loss increases, the masking effect of the ambient noise decreases."

The constancy of the ambient noise in the test room is more important than the absolute noise level. If the noise level is constantly changing then so is its masking effect and consequently the recorded threshold value. The noise in the test room was found to be reasonably constant. The results in the three fifteen minute periods during which the noise level was recorded at one minute intervals, are given in table XXX (page 137). It can be seen from this table that in the three periods 86%, 94% and 73% of the readings fell within ± 2 db. of the mean and 93%, 100% and 93% of the readings fell within ± 4 db. of the mean. Hence the ambient noise level was maintained at a fairly constant level within the test cubicle. Consequently, we can assume that at a constant threshold level, changes in threshold resulting from changes in ambient noise masking would be very slight. However, as we have just noted, the masking effect would vary with changes in the threshold. The higher the threshold, the less the masking effect. Since we are dealing with threshold increases the amount of error resulting from masking would increase as the amount of TTS increased. Subjectively, in view of the low constant noise levels, the author feels that these errors are only very slight.

An important point about the test cubicle is that further improvement would probably have resulted in another difficulty. Professor McElwee[1] has pointed out that persons working in completely sound-proof and anechoic rooms are liable to suffer from fits of panic which are very similar to claustrophobia. The author has also found this to be the case. Thorpe and Hinde (1956) have also stated that an intensity of 40 ± 3 db., on the 'C' weighting of a Dawe sound level meter, is less than the noise level produced by the respiration, blood-circulation and heart beats of a human subject. Hence, although psycho-acoustically a completely sound-proof room represents the optimum conditions, this is not a practical proposition.

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CHAPTER XVII

The Békésy Method.

The control experiment on the Békésy method showed that the Békésy method of threshold tracing produces aperiodic, cyclical variations in the absolute threshold of auditory sensitivity which are larger than the similar changes produced by the modified method of limits (see pages 111 to 130). The differences between these two methods indicate that the Békésy method is less reliable, when the threshold is traced for long periods at one fixed test frequency.

The subjects and the test conditions were the same in the two tests apart from the use of the Békésy method in one case and the modified method of limits in the other. Normal intra-subject variability cannot account for the results since all of the subjects were consistent in showing reduced variability when the modified method of limits was used to measure the threshold. It might be argued that the difference between the two methods is artificial, in that the Békésy method allows the subject to make more responses in a fifteen minute test period. Inspection of figures 22a to 22f and 23a to 23f reveals that the subjects made 47 responses in the method of limits experiment; but that they made from 40 to 102 responses, with a mean of 71.5 responses, in the Békésy method. This objection fails, since although it would adequately explain the differences in the amount of oscillation, it would not explain the differences in the amplitude of oscillation. Figures 23a to 23f are completely different from figures 22a to 22f, whereas if the above argument held, then we would expect them to be both qualitatively similar to the earlier parts of the latter figures.

We must conclude that the greater constancy of the threshold obtained using the modified method of limits results from the differences between this method and the Békésy method. We must also conclude that either the two methods utilize different subjective response systems or alternatively the two methods have different effects on the variability of the same common subjective response system.

A priori, it would appear that the responses a subject makes in any threshold determination are dependent upon at least three factors. These are :

(i) The general sensitivity of the subject (This will include such factors as local fatigue, central fatigue and attention).

(ii) The criterion of response that the subject adopts. (Does he, for example, judge when doubtful, sure or certain?)

(iii) The responses he has already made.

All of these factors can be expected to affect both the Békésy and the modified method of limits method. However, the first two factors would over a long testing period affect both methods equally. Consequently, we would not expect them to cause any differences between the two methods. Hence, it would appear that the decisive factor in differentiating the methods lies in the responses that the subject has already made.

The essential difference between the two methods is that in the modified method of limits the subject is always returned to two fixed reference points. These referance points are the extremes between which the attenuation is varied by the experimenter. It has been pointed out (see page 61) that the subjects always responded to the tone at the upper intensity limit; whereas they never responded to the tone at the lower intensity limit. Consequently, it can be assumed that the subject always heard the tone at the upper intensity limit and he never heard the tone at the lower intensity limit. The fixed reference points were chosen with this criterion in mind. The advantage of providing reference points is that they provide the subject with a standard on which to base his responses. They are not present in the Békésy method, where the intensity of the tone increases or decreases as soon as the subject decides he does not, or he does hear the tone.

The presence or absence of reference points in a response system is related to recent work of Pollock (1956) on elementary display systems. He suggests that basically there are three procedures that can be used in allowing a subject to make a response to a display system. These are:

(i) The observer categorizes the stimuli by choosing the correct category from memory.

(ii) The observer categorizes the stimuli after a further presentation of the catalogue of category responses.

(iii) The observer categorizes the stimuli with the catalogue of responses available to him at all times so that he can refer to it as and when he requires to.

Pollock suggests that (i) and (ii) are identification systems in which the subject must recognize the stimulus and that (iii) is a discrimination system in which the subject has to compare the stimulus with a series of standard stimuli.

A consideration of the Békésy and the modified method of limits techniques indicates that they are respectively similar to Pollock's first and second display techniques. Both are identification systems insofar as the stimulus must be heard and recognized. Both methods involve categorization, since at any instant in time the subject must categorize the stimulus as being present or absent. In the Békésy technique, the subject has no reference to any confirmatory stimulus on which he can base his responses. Consequently it equates with Pollock's first display technique. In the modified method of limits, the subject makes a response and is subsequently presented with the fixed reference stimulus. This enables him to check the validity of his response. It is essentially similar to Pollock's second display technique. However, it does differ in that Pollock allowed his subjects to make their decision after presentation of the comparison signal. This latter difference probably increases slightly the errors made using the modified method of limits technique.

Pollock studied the effectiveness of the three procedures in audition and found that the first procedure produced more errors than the second procedure and the second procedure produced more errors than the third procedure, unless the differences between scale categories were very coarse. He also found that as the "fineness" of the scale of category responses was increased so were the differences between the three procedures. The greater effectiveness of the second recognitio technique is similar to the differences between the Békésy and modified method of limits techniques.

The effect of the reference points seems to be closely associated with anchoring of response scale effects. Guildford (1954, page 312) points out that the effect of an anchoring stimulus is to shift the judgements in a response scale towards the anchoring stimulus. He also points out that the further removed a stimulus is from the anchoring stimulus the greater the anchoring effect. The fixed reference points in the modified method of limits method appear to form a high and a low intensity anchoring stimuli. The high intensity anchor is intensity at which the tone is always responded to and the low intensity anchoring stimulus is the intensity at which the tone is never responded to. Since these affect the stimuli furthest away from them, they result in a compression in the scale of responses with a consequent reduction in the variability of responses. When they are introduced together, then their joint affect is an even greater compression of the scale of responses and the consequent reduction in the variability of responses.

The greater variations in the threshold produced by the Békésy method can also be explained in terms of the effects of anchoring stimuli, However, in this method there are no fixed anchoring stimuli. Consequently the stimuli to which the subject has just responded become the anchors. In this situation the scale of responses for any pair of responses, that is between a response of hearing and not hearing the tone or vice-versa, becomes concentrated between these two responses. The work of Békésy (1947) has shown the range between a hearing and not hearing response seems relatively invariant with constant test conditions. These two effects seem to add together and produce a gradual upward or downward movement of the threshold. This is illustrated in figure 34 which is a theoretical diagram drawn on the assumptions that the subject responds at a point midway between the two previous responses which form the anchoring stimuli, that the

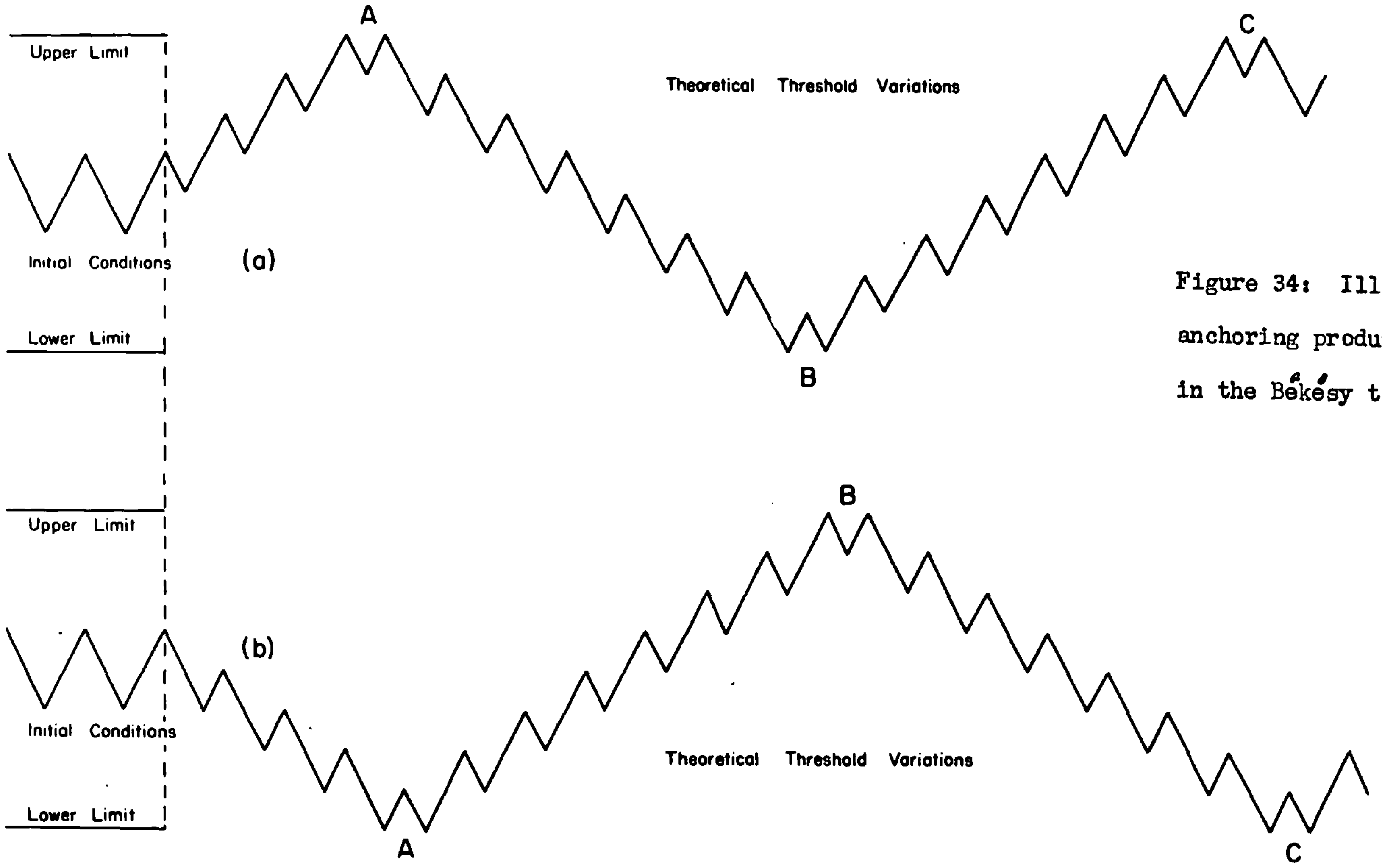

Figure 34: Illustrates how anchoring produces aperiodic variations in the Békésy threshold.

length of the excursions remains constant and that these two conditions follow in order. In diagram 34a, the subject gives a not hearing response mid-way between the previous hearing and not hearing response. This is followed by a normal pen-excursion and this in turn is followed by a response mid-way between the previous two responses. This continues and results in a gradual elevation of the threshold. A similar effect occurs in figure 34b, except that in this case the subject makes a hearing response mid-way between the previous not hearing and hearing responses. This results in a gradual reduction in the threshold.

The gradual increases or reduction in the threshold are limited by two factors. The first of these factors is the extreme limits of intensity, above and below these the subject always responds or does not respond respectively. The anchoring stimuli may widen the range between these limits, since the probability of response to a tone will be affected even at the extremes by the anchoring stimulus. However, this effect will be limited since at a given intensity, the increase in intensity will overcome any effects the anchoring stimulus may have. The second factor limiting the increases or reduction in a tone is the changes in the probability of response to a tone as the above limits are reached. The probability of response increases from 0 to 100% between the limits either in quantal or in a sigmoidal manner (see Stevens, 1951). The manner of variation is unimportant. Whether the changes are quantal or sigmoidal, the changes mean that the nearer the intensity to the intensity below which the subject never responds, the less the probability of a "hearing" response. Similarly, the nearer the intensity to the intensity above which the subject always responds, the less the probability of a "not hearing" response.

The effect of these factors is seen in figures 34a and 34b. In figure 34a the upper limit of responses is reached at point A and the lower limit at point B. In figure 34b the lower limit of responses is reached at point A and the upper limit at point B. When these points are reached, the pattern of responses is broken since the subject cannot maintain the successive mid-point equal excursion series.

He must respond or not respond to the tone when the intensity limits are reached. However, once the sequence is broken in one direction it commences in the opposite direction. Hence the changes in threshold become reversed. At point C in figure 34a and figure 34b, there is a further change in the direction of the threshold changes because of changes in the probability of response.

The assumptions of successive mid-point, equal excursion responses will not of course hold in actual practice. However, a change in threshold in one direction will tend to perpetuate itself for the following reasons :

(i) The anchoring effect will tend, depending on the direction of travel, to produce a response at a lower or higher intensity than the previous response of the same nature.

(ii) The anchoring effects will tend to be obviated on excursions moving in the direction of travel by changes in the probability of response in that direction.

(iii) The anchoring effects will tend to be accentuated on excursions moving in the reverse of the direction of travel by changes in the probability of responses in that direction.

We have already noted that this tendency to perpetuate the threshold changes will be overcome because of changes in the probability of response or because the limits of responding or not responding have been reached. However, since the subject <u>may respond or not respond</u> at any point between these limits, a change in the direction of the threshold changes can occur at any point between them. There is simply a greater probability of them occuring towards the extremes. The validity of this suggestion is increased when we consider the distribution of random numbers. Random numbers show qualitatively similar aperiodic oscillatory tendencies (see Yule and Kendall, 1950, page 376) to those produced in the Békésy method. If we assume that the probabilities of response to the tone are sampled in a random manner, then this supports the above hypothesis.

The above explanation also explains the slight negative correlation between the amplitude and the amount of oscillation. It can be seen that as the amplitude of the oscillation increases, the subject spends more time travelling between successive peaks and valleys. Consequently the number of oscillations in a fixed time interval is reduced. Frequency differences in the amplitude of oscillation were found not to be significant (see page 119). This latter finding suggests that the range between always responding and always not responding is relatively invariant with frequency. This finding is supported indirectly by work of Békésy (1929) which showed that the difference limen for intensity is independent of the test frequency.

The amount of oscillation was found to be maximal at 1500 cps (see page 115). This does not associate itself with any other known phenomenon in audition. Various studies have placed minimal threshold at frequencies between 1000 and 5000 cps (see Hirsh, 1952, page 107). It might be that minimal threshold occurs at 1500 cps since this frequency is seldom tested. However, Luscher and Zwislocki (1947) claim quite definitely that minimal threshold is at 3000 cps. The effect is probably associated with the cochlea since Wever (1949 and 1950) has shown that the limits of linearity of cochlear potentials are reached at 1500 cps and that blocking the oval window produce maximal hearing loss at 1500 cps. How this correlates with the above phenomenon is difficult to conceive. It may be that Wever's results indicate that the ear is most sensitive at 1500 cps and that carefully controlled laboratory studies would reveal this. If this is the case, then the greater sensitivity of the ear would also probably result in a greater variability of the results around threshold level. Consequently the effect would be explained. Even if this is not the case, Wever's results do indicate that 1500 cps is a transition frequency. Something, as yet unknown, occurs in cochlear responses at this frequency. In this case it seems likely that this transition process will accentuate the probability - anchoring effects postulated above. This highly unsatisfactory answer seems to be the most satisfactory one that can be offered at present.

The postulated anchoring effects also explain the absence of aperiodic, cyclical changes when the threshold was traced for short periods in the two control experiments studying threshold shifts in the absence of the stimulus tone. In the first of these the stimulus tone was replaced by silence. This possibly formed an anchoring stimulus. The effect of this apparently lasted for the three minute post-exposure threshold tracing. Alternatively the anchoring stimulus might have been the above threshold tone which was heard by the subject at the commencement of all tracing sessions. This seems more likely since we have already seen that the differences between the thresholds for successive periods of tracing were slight; and in the control experiment studying Békésy tracing with two minute rest periods, the only possible anchor would be the commencement tone. This was the stimulus heard during the non-tracing periods and consequently it forms the only anchoring stimulus. Whether the commencement tone or silence are the anchoring stimuli, the important point is that they provide <u>fixed reference stimuli</u>. We have already seen in the modified method of limits such fixed reference or anchoring stimuli reduce the amount of threshold variations, and their absence increases the amount of threshold variation during Békésy tracing.

Fortunately, the variability in threshold measurements resulting from the use of Békésy technique does not appear to have greatly affected the experiments on TTS. The above control experiments utilizing tracing for short periods showed that under these conditions, only the introduction of an appropriate stimulus tone produces an elevation of the threshold. However, these experiments only dealt with the mean threshold which is the threshold that is considered in the TTS experiments. It would appear likely that the phenomenon would effect the results obtained on specific threshold readings over very short periods of time. Readings of this nature are involved in the studying of diphasic recovery phenomenon. The control experiment in which recovery from TTS was studied using the modified method of limits (see pages 130 to 133) confirmed the validity of this suggestion. Hence, as we have already noted, we must view the results obtained in the experiments on recovery, in which thresholds were measured using the Békésy method, with some reserve.

These experiments do throw a great deal of suspicion on the reliability of Békésy recordings made over long periods of time at a fixed frequency. The phenomenon has not been referred to before except for the brief references by Békésy (1947) and Epstein and Schubert (1957) These workers also suggest that the amplitude of the changes is of the order of approximately 5 db. This result agrees fairly well with the mean amplitude of 6.623 db. obtained in the author's results (see table XXll, page 117). However, a consideration of the remainder of this table indicates that this is only a mean value. The frequency variations cover a mean range of amplitudes from 4.51 to 7.66 db. and the subject variations cover a mean range of amplitudes from 3.69 to 10.81 db. Within the table the mean amplitudes range from 1.21 db., for subject F at 1500 cps to 14.84 db., for subject A at 1000 cps. Consequently, we must conclude that the threshold variations are much larger than suggested by either Békésy or Epstein and Schubert, who did not make a study of specific detail of these variations.

Then obvious implication of these results is that more research is required on the use of Békésy audiometry in clinical audiometry. Many of the tests for malingering such as the Stenger test (see Newby, 1959, pages 157 to 159) utilize threshold measurements at fixed frequencies for fairly long periods. Should the Békésy technique be used for these tests, then it would appear that the results may be seriously impaired by the above phenomenon. The effect of the Békésy technique on the audiograms obtained with a continuously varying frequency is not known. The effect of varying frequency may reduce the amount of threshold variation. However, this seems unlikely, since the subject will still have no fixed reference or anchoring stimuli and the results of Békésy (op.cit.) and Epstein and Schubert (op.cit.) were obtained under these conditions.

Attenuation rates will almost certainly have some effect on the amount of threshold variation. Only one attenuation rate was used in this study and consequently we have no direct information available. Corso's (1956) work showed that attenuation rate did not effect the mean threshold but since he used short test periods, this only confirms the results of the control experiments which showed no significant variations of threshold readings with short test periods. Other studies have also used much faster attenuation rates than was used in the present study. It may be that this will reduce the variation of threshold readings. Backlash (see page 43) will tend to carry the subject much nearer or even into the range of complete audiability and complete inaudiability with the faster attenuation rates. Consequently, the method under these circumstances may equate more closely with the modified method of limits. However, more research is needed on the phenomenon.

We may conclude that the Békésy method appears to be affected by anchoring, just as the more conventional modified method of limits is. The effects within the two techniques are mediated differently and this difference affects the threshold as measured by the Békésy method over long periods. A great deal of further research is required; but these initial results would seem to place very stringent restrictions on the Békésy method. Should further research confirm this then it is fortunate that automatization of the modified method of limits technique could be achieved fairly simply. The use of the Békésy method does not affect the recordings of mean TTS provided the pre-exposure and post-exposure test periods are of short duration. However, it does affect the manifestation of phenomena such as diphasic recovery which are observable in terms of instantanious rather than of mean threshold.

APPENDICES.

Appendix 1.

Technical Details of the Equipment Used.

Channel 1: Consisted of an audio-tester and two attenuators. The audio-tester was a Marconi (Type T.F. 894A) calibrated from 50 c.p.s. to 27 k/c.p.s. and designed to work to a 600, 15 and 3 ohm output. The frequencies are accurate to ± 2% ± 5 c.p.s. when the instrument has reached thermal equilibrium, and the output distortion is 1.5% of the total at 1.5 watts and 2% of the total at 2 watts, when the frequencies are between 100 and 8000 c.p.s. The audio-tester is itself capable of 50 db. attenuation. The first attenuator in the circuit was used to extend this range and was an Advance Low Frequency Attenuator (Type A 64) having an input and output impedance of 600 ohms and giving 70 db. of attenuation in 1 db. steps. The second attenuator was a Marconi Attenuator (Type 338 C) and was converted into a subject/experimenter controlled attenuator (see Appendix II). This also has an input and output impedance of 600 ohms. It provides 80 db. of attenuation in 20 db. steps and 25 db. of continuously variable attenuation.

Channel 2: Consisted of an oscillator and two attenuators. The oscillator was a Wein Bridge Oscillator constructed from a circuit published by Williamson (1956). It has a frequency range of 3 cps. to 330 k/cps in five decade steps. Williamson claims that the harmonic content of the tones is less than 1% at 2 k/cps., that the amplitude linearity is 0.025 db. from 15 cps to 330 k/cps. and that the frequency drift over a three hour period is negligible. The two attenuators were Advance Low Frequency Attenuators (Type A64, see Channel 1) and provided 140 db. of attenuation in 1 db. steps.

Mixing: The outputs from the two channels were fed through a two-pole change-over switch, so that either channel could be selected as necessary. The selected output was fed into the standard earphone, via a Gardner's transformer (GR 11471) which has an input impedance of 600 ohms and an output impedance of 25 ohms. This matched the impedance of the output from either channel to the impedance of the standard earphone. The latter was manufactured by Standard Telephones and Cables (Type 4026A, Head Receiver). It is a moving coil type of instrument with a frequency response 50 cps. to 10 k/cps. It was calibrated at the National Physical Laboratory, Teddington (see Appendix III).

Appendix 11.

Conversion of Marconi Attenuator.

The conversion of the Marconi attenuator to a subject/experimenter controlled attenuator was achieved in the following way.

(i) A 12 volt government surplus reversible D.C. electric motor of unknown specifications was connected to a worm-gear by means of an insulated flexible drive.

(ii) The worm-gear connected through a series of other gears to a gear attached to the shaft of the continuously variable control of the attenuator (see plate Vl, page 49).

(iii) Hence activation of the motor resulted in movement of the attenuator dial. The rate of movement could be altered by changing the positions of the gears referred to in (ii).

(iv) The direction of drive of the motor was simply controlled by connecting the subject and the experimenter switches to two relays (A and B). If either switch were closed Relay A closed and Relay B opened. If either switch were open the reverse occured. By reversing the current flow through Relay A and Relay B, the motor revolved in one direction when the control switches were closed and in the other direction when the control switches were open.

(v) Micro-switches were placed at the extremes of the attenuator dials. The switch at the lower end of the dial short-circuited the two relays and stopped the motor. The switch at the upper end of the dial rapidly reversed the relays and consequently the motor "hunted" backwards and forwards. This prevented the attenuator being driven past its limits.

(vi) The shaft of the continuously variable control of the attenuator was coupled, via a flexible drive, to an elongated worm-gear. Coupled to the worm gear was a block containing a pen. Hence any movements of the attenuator dial were reproduced in the pen.

(vii) Movements of the pen were recorded on a strip of paper. This was kept moving by a friction drive, activated by an electric motor, at a constant speed of one inch per minute.

(viii) The continuously variable control of the attenuator was linear over most of its range. Hence as long as the attenuator was working on this range the linear motion of the pen was directly related to the amount of attenuation.

Appendix 111.

Copy of Calibration Chart for Standard Earphone

TEST CERTIFICATE

FOR

4026-A HEAD RECEIVER.

SERIAL NO. 2385

This certifies that the above receiver has been mechanically and electrically tested and is satisfactory.

The response in db. above 1 dyne per sq. cm. per volt is given below:-

Frequency c/s	Response db.
125	57.4
250	57.1
500	55.3
1000	53.4
1500	52.7
2000	52.6
3000	53.0
4000	53.2
6000	45.6
8000	49.9

Calibration reference: BS.2042 : 1953 Fig la & 2b

Date of Calibration: 4.2.60

ST.439471

Appendix IV

Screening

Procedure : After the subjects had completed their practice sessions they were carefully screened by means of two tests to eliminate any subjects suffering from abnormalities of hearing or heightened susceptibility to TTS.[1] The two tests used for this purpose were :

(i) Measurements of the absolute threshold of hearing by a modified method of limits.

(ii) A modified test for abnormal susceptibility to TTS adapted from a "recruitment test" devised by Carhart (1957).

Threshold measurements were taken at frequencies of 500, 1000, 2000, 3000, 4000, 6000 and 8000 cps. The subjects were tested monaurally using only the first channel of the apparatus. During these measurements the modified Marconi attenuator was used as an ordinary continuously variable attenuator, not as a subject/experimenter controlled attenuator. The subjects were tested monaurally on both ears.

The procedure adopted in these tests was as follows :

(i) The subject entered the test room and was shown the switch controlling the signal light system. They were instructed to press the signal light switch when they could hear a tone and to release it when they could not hear the tone, i.e. to keep the signal light off when they could hear the tone and to keep the signal light on when they could not hear the tone.

(ii) Before the testing began, the intensity of the tone was reduced to well below the subjects' threshold.

(iii) When the subject was settled in the test room the intensity of the tone was increased in 5 db. steps until he responded to it. The intensity at this point was noted.

(iv) The intensity of the tone was decreased to 10 db. below the intensity noted in (iii) and then increased in 1 db. steps until the subject again responded to the tone. The intensity at this point was recorded.

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[1] This was done mainly for ethical reasons. Such subjects could have possibly suffered from permanent hearing losses.

(v) The intensity of the tone was increased to 10 db. above the intensity noted in (iii) and then decreased in 1 db. steps until the subject ceased to respond to the tone. The intensity at this point was recorded.

(vi) The threshold was determined by taking the mean of the two values obtained in (iv) and (v).

Judgements on the suitability of subjects for inclusion in the experiment were made by comparing the threshold values determined in the above manner with values obtained by Sivian and White (1933) and by assessing the general frequency-threshold relationship.

Since the testing was carried out under laboratory conditions, it was decided to use laboratory rather than field surveys for comparison purposes. It was also decided to use a laboratory study in which measurements were made in terms of Minimum Audible Pressure rather than in terms of Minimum Audible Field. The former equates more closely to the technique and earphone calibration used in these experiments. The choice of Sivian and White's data was arbitary. Other data, such as that of Waetzmann and Keibs (1936) would also have fulfilled the above conditions. However, the discrepancies between the available studies were not large enough to have seriously affected the acceptance or rejection of subjects. The screening criterion was that the subject should not exceed the threshold values obtained by Sivian and White by more than 10 db. at any test frequency. The 10 db. criterion was chosen, since Steinberg and Munson (1936) have obtained a standard deviation of 3.1 db. for individual variations in absolute threshold measurements.

The modified "recruitment test" was thought to test abnormal susceptibility to TTS. Carhart noted that in cases of end-organ deafness "adaptation of the ear to tones around the threshold occurs very quickly." He claimed that subjects failing to respond to a test tone for 60 seconds at 0 or +5 db. re their threshold are suffering from recruitment, i.e. pathological end organ damage. Because of possible errors in the threshold measurements used for screening in these experiments, it was decided to modify Carhart's criterion. The revised criterion is given below.

The following procedure was adopted in administering the test:

(i) A tone of a given frequency was adjusted to 10 db. below the threshold value determined for that frequency in the threshold screening test outlined above.

(ii) If the subject failed to respond to the tone at 10 db. below threshold value its intensity was increased in 5 db. steps until he did respond to it.

(iii) When the subject responded to the tone then the tone was maintained at this intensity level either for 60 seconds or until the subject stopped responding to the tone if this was less than 60 seconds. The time of response to the tone was recorded.

(iv) Immediately the tone had been applied for 60 seconds or immediately the subject stopped responding its intensity was raised by 5 db.

(v) The procedure described in (iii) and (iv) was repeated until the intensity of the tone had been raised to 10 db. above threshold.

The test was administered at 1000, 4000 and 8000 cps. To facilitate measurement and to counteract the effects of intra-subject threshold variation, each tone was tested after the completion of the screening, threshold measurements at that frequency. The criteria used for screening purposes were :

(i) Whether or not the subject responded to the tone for one minute at or below an intensity level of 10 db. re his threshold for the particular tone being tested.

(ii) Whether or not the range of intensities required to obtain this a one minute response was greater than 10 db.

The subject was required to pass the screening criterion at all three test frequencies for inclusion in the experiments.

Results : The results for the first test are shown in table Ia. At the top of the table is given the results obtained for 'normal' threshold measurements obtained by Sivian and White (1933) using Minimum Audible Pressure. These and the experimental results are taken

Table Ia

Screening threshold measurements obtained using a modified method of limits for each of the twenty four subjects used in the experiments. For comparison purposes data derived from Sivian and White's (1933) study are shown. Results are given to the nearest db.

Threshold re. 0.0002 dynes/cm^2 at each frequency given in cps.

Subject	500cps	1000cps	2000cps	4000cps	6000cps	8000cps
Sivian & White (MAP)	17	10	5	11	15	20
A	14	8	7	12	13	20
B	27	15	5	9	9	9
C	4	-8	-9	-5	0	18
D	-10	-16	-16	-11	5	8
E	19	12	3	10	10	19
F	12	12	-1	3	9	13

Table 1 (continued)

Subject	500cps	1000cps	2000cps	4000cps	6000cps	8000cps
G	20	8	-5	-3	5	10
H	10	4	4	3	5	15
J	25	14	9	10	13	19
K	-1	-8	-13	-8	-5	3
L	-5	-9	-7	-12	-3	-2
M	19	12	9	6	6	29
N	16	14	14	18	20	25
O	-6	-8	-12	0	5	5
P	8	6	7	9	14	17
Q	25	12	12	11	15	17
R	9	5	3	8	13	18
S	15	7	9	8	12	21
T	20	13	12	14	17	22
U	12	6	5	5	19	25

Table 1 (continued)

	500cps	1000cps	2000cps	4000cps	6000cps	8000cps
Subject						
V	18	13	7	9	15	19
W	12	5	7	8	19	27
X	-1	-5	-7	-2	5	11
Y	5	6	3	9	14	24
Mean	11.33	5.00	2.24	1.64	10.08	16.76
Standard Deviation	9.87	8.63	8.39	8.95	7.40	7.90

Table IIa

Results obtained using Carhart's test for abnormal susceptibility to TTS for each of the twenty four subjects used in the experiments. Results in the body of the table are the time in seconds for which the subject responded to the tone. A dash denotes that the test was discontinued.

Subject	Intensity of sound in db. re subjects threshold.			Frequency
		1000	4000	8000
A	-10	0	0	0
	-5	18	0	7
	0	60	45	52
	+5	-	60	60
	+10	-	-	-
B	-10	0	0	0
	-5	49	0	19
	0	60	0	38
	+5	-	60	60
	+10	-	-	-
C	-10	9	0	0
	-5	60	0	0
	0	-	0	54
	+5	-	33	60
	+10	-	60	-
D	-10	0	3	0
	-5	54	47	38
	0	58	60	60
	+5	60	-	-
	+10	-	-	-
E	-10	0	0	0
	-5	60	0	0
	0	-	53	29

	+5	-	60	60
	+10	-	-	-
	-10	0	0	0
	-5	0	0	18
F	0	33	27	60
	+5	60	60	-
	+10	-	-	-
	-10	0	0	0
	-5	41	0	18
G	0	60	0	48
	+5	-	60	60
	+10	-	-	-
	-10	0	0	0
	-5	0	60	0
H	0	32	-	21
	+5	60	-	60
	+10	-	-	-
	-10	0	0	0
	-5	0	0	0
J	0	60	47	5
	+5	-	53	60
	+10	-	60	-
	-10	0	0	0
	-5	0	0	0
K	0	18	47	0
	+5	60	60	18
	+10	-	-	60
	-10	0	0	0
	-5	0	0	0
L	0	59	18	52
	+5	60	57	60
	+10	-	60	-

M	-10	0	0	0
	-5	60	0	0
	0	-	0	44
	+5	-	60	60
	+10	-	-	-
N	-10	0	0	0
	-5	32	0	0
	0	60	0	0
	+5	-	60	52
	+10	-	-	60
O	-10	0	0	0
	-5	0	15	0
	0	5	60	0
	+5	60	-	60
	+10	-	-	-
P	-10	0	0	0
	-5	0	0	0
	0	60	8	0
	+5	-	15	37
	+10	-	60	60
Q	-10	0	0	0
	-5	0	0	0
	0	28	12	5
	+5	57	60	49
	+10	60	-	60
R	-10	0	0	0
	-5	0	19	0
	0	0	60	32
	+5	60	-	60
	+10	-	-	-

	-10	0	0	0
	-5	0	0	0
S	0	0	12	0
	+5	35	27	37
	+10	60	60	60
	-10	0	0	0
	-5	0	22	0
T	0	54	38	46
	+5	60	60	60
	+10	-	-	-
	-5	60	16	0
U	0	-	38	47
	+5	-	60	60
	+10			
	-10	0	0	0
	-5	0	12	29
V	0	60	51	59
	+5	-	60	60
	+10	-	-	-
	-10	0	0	0
	-5	53	0	3
W	0	60	18	49
	+5	-	60	60
	+10	-	-	-
	-10	0	0	0
	-5	0	29	11
X	0	18	60	30
	+5	60	-	60
	+10	-	-	-

	-10	0	0	0
	-5	0	0	31
Y	0	0	4	60
	+5	60	60	-
	+10	-	-	-

to the nearest db. It can be seen from the table that at the frequencies tested, none of the twenty four subjects exceeded the values obtained by Sivian and White by more than 10 db. and that none of them diverged greatly in the general frequency-threshold relationship apparent in Sivian and White's data.

The results for the second screening test are presented in table 11a. It can be seen from the table that, at the frequencies tested, none of the twenty four subjects used in the experiment failed to respond to the tone for a full minute at an intensity 10 db. or less re their threshold. It can also be seen from the table that none of the subjects required a range of intensities of greater than 10 db. to obtain a full minute's response to the tone.

Hence, all the subjects' used in the experiment passed the two screening tests and were suitable for inclusion in the experiments on TTS.

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